ARMY RESEARCH LABORATORY

A Comparison of Heat Accumulation in the M3A2 and M3A3 Bradley Fighting Vehicles

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Abstract

Field data suggested that the Bradley M2/M3 fighting vehicle A3 upgrade subjected the crew to greater heat stress than the previous system did. A study was conducted to determine if the Bradley A3 crew stations were hotter than those of the A2 and if so, what the operational implications were for crew performance.

A Bradley A2 and A3 were place side by side in an environmental chamber and exposed to 30°, 40°, 80°, 100°, and 125° F with the hull fans off; to 80° and 100° F with the hull fans on; and to 80° F with one hull fan on. In addition, the vehicles were exposed to a 10-hour segment of the standard "basic hot" environmental scenario[1], with hull fans on and off. Finally, the vehicles were run through a series of brief excursions to evaluate engine temperatures. During all testing, temperature data were collected at the driver's station, turret, and squad area at head, hand, and foot heights. Additional sensors recorded relative humidity, pressure, and additional temperatures in the vehicle. Smoke candles were used to evaluate air movement through the vehicles during a side test.

Results showed that temperatures were consistently higher (between 10° and 35° F) in the A3 driver's compartment than in the A2 when the vehicle's hull fans were off. Based on the smoke test, this appears to be caused by the turret fan creating an under-pressure that draws air into the driver's area from the engine.

With the hull fans on, the A3 driver's compartment is between 2° F warmer and 4° F cooler than the A2. The A3 turret is still 5° to 8° warmer. This difference was not operationally significant. At 80° F, both the A2 and A3 were within acceptable limits. At 100° F, both vehicles exceeded recommended heat limits (85° F wet bulb globe temperatures [WBGT]). In the A2, the worst (limiting) locations were driver head and driver hand, with a maximum exposure of 1 hour. In the A3, the worst locations were driver head and turret foot, with a maximum recommended exposure of 1.2 hours.

The conclusion was that the A3 is substantially warmer than the A2 when the hull fan is off but not when the hull fan is on. In environments above 80° F, either vehicle would benefit from reduced internal temperatures.

[1]MIL-STD-810E

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1. Introduction

1.1 Background

The M2/M3A3 is an improved version of the M2/M3 family of armored Bradley fighting vehicles (BFVs). It includes changes to achieve greater integration with current command and control systems than earlier M2/M3 variations were capable of achieving.

A concern existed that the additional electronics in the BFV A3 might increase the heat load unacceptably in the crew areas. A test conducted in an environmental chamber at 125° Fahrenheit (51.7° C) found the temperature to be generally lower in the BFV A3, except for one reading at the driver's station of 99° F in the BFV A2 and 100° F in the BFV A3 (United Defense, 1997).

However, field tests have identified excessive heat accumulation, especially in the driver's compartment, to be a potential problem. During the Limited User Test, phase 1 (LUT-1) and gunnery trials, the driver's station was found to be substantially warmer than the turret in the A3. In temperate conditions, this may have been because the heater was on and the hatch was open in the turret, and heat vented from the turret to the driver's station where the hatch had to be closed. Another explanation was that the fire wall between the driver and the engine was 20° to 30° F warmer than the ambient environment.

As a result of these two conflicting results, it was unclear if the A3 could meet the requirement that it be no hotter than its predecessor.

1.2 Objective

The objective of this evaluation was to identify if the BFV A3 was subject to greater heat accumulation than the BFV A2. If a difference was found, it was to be quantified in order to determine if it was meaningful in terms of crew performance.

As a secondary objective, the evaluation was intended to contribute to a profile of thermal accumulation in the M2 family. This may be used in future development efforts to define cost versus performance trade-offs provided by crew cooling systems.

2. Methodology

2.1 Participants

There were no direct human subjects in this study. U.S. Army Test Center (ATC) personnel performed vehicle instrumentation and data collection. Personnel from the Tank Automotive Command (TACOM), Operational Test and Evaluation Command (OPTEC), and the Human Research and Engineering Directorate (HRED) of the U.S. Army Research Laboratory (ARL) were on site as needed to observe. Data reduction and analysis were completed by ARL.

2.2 Apparatus

2.2.1 M2A2 and M2A3 Vehicles

One M2A2 and one M2A3 Bradley, each configured with similar mission equipment, were used in this study. Except for changes proposed in the A3 revision, these vehicles were as similar as possible. The M2A2 had serial number 2AD20583 with engine serial number 37159664. This is a standard M2A2 without the Operation Desert Storm modifications. The M2A3 had serial number A3-32.

Both vehicles were equipped with white smoke engines. The vehicles were inspected by ATC before testing to ensure that they were operating properly. Both vehicles were fueled from the same source at the beginning and as needed throughout the test. For the duration of this test, neither vehicle had on-board stowage or a weight kit. During testing, all hatches of both vehicles were closed, as was the turret door to the interior squad area.

2.2.2 Environmental Test Chamber

This test was conducted at Aberdeen Proving Ground in Building 450, which contains an environmental chamber capable of achieving and maintaining a variety of combinations of temperature, humidity, air flow, and solar load. It is capable of containing two Bradley vehicles to allow side-by-side testing.

2.2.3 Thermal Measuring Devices

The environmental test chamber includes instrumentation to measure dry-bulb temperature at head, hand, and foot locations and one measurement of relative humidity at head locations at each crew station (driver, turret, and squad area) at head, hand, and foot locations.

A number of other conditions were recorded to characterize the test environment. Additional dry-bulb temperature readings were taken at the output of each vehicle's heater. Sensors were placed to record when the vehicle's vent fans are on. Finally, temperature, humidity, and solar load defining the exterior ambient conditions were recorded. These data were digitally recorded in real time and were down loaded for reduction and analysis.

At the later stages of the test, temperature sensors were added in the engine compartment. Photographs of the sensor locations are available in Appendix A.

2.2.4 Other Instrumentation

A digital data collection system was used to monitor the digital communications data bus activity within the M2A3. The actual processor and recorder were outside the chamber and did not influence vehicle or chamber heat load. Recording data bus activity was a secondary task not related to this test; the Program Manager's Office will conduct the analysis of these data.

In addition to the test chamber instrumentation, a pair of WIBGET® heat stress monitors measured wet bulb globe temperatures (WBGT) during a sub-test. This was done to validate the translation of chamber measurements into WBGT and to provide a comparison if the WIBGET® monitor is needed to support future field exercises. WBGT is a combination of dry bulb temperature, wet bulb temperature (which includes humidity and air flow), and solar load.

2.3 Procedure

The test was segregated into eight days of testing in a static condition, two days of changing temperature and solar load simulating a day cycle, and one day of short excursions. In all conditions, the engine idled and the exhaust was routed outside. In all conditions, the driver's hatch and the turret hatch were closed. Induced air flow (fans used to simulate wind) was not used in any condition. The test schedule is shown in Table 1.

Since the solar loading panels did not fully cover both vehicles, the vehicles were parked in the chamber to ensure that equivalent areas of each vehicle received comparable solar loading. When not otherwise specified, testing procedures adhered as closely as possible to those outlined in military standard MIL-STD-810E, section 501 (Department of Defense, 1989).

The eight days of testing in a static condition were designed to compare the temperatures of the M2A2 and M2A3 in a stable, highly controlled environment. Testing in a static condition began with both vehicles in the chamber which was set to the experimental temperature and humidity for that cell for about 6 hours (24:00 to 06:00). After both vehicles had been "soaked" in the test environment

for 6 hours, the engines were started and hull fans were set to the day's test conditions. Chamber operators monitored the vehicle interior temperature until it had reached a steady state (head, hand, and foot sensors at driver, turret, and squad locations in both vehicles remaining stable ±2° Fahrenheit) for 2 hours.

Table 1. Test Schedule

Day	Temperature (degrees F)	Relative humidity rH (%)	Solar load (w/m^2)	Hull fans	Turret fans
1	Day Scenario (14-hr duration)			Off	Auto
2	30	--	730	Off	Auto
3	40	50	730	Off	Auto
4	80	50	730	Off	Auto
5	80	50	730	On	Auto
6	100	50	730	Off	Auto
7	100	50	730	On	Auto
8	125	--	730	Off	Auto
9	Day Scenario (14-hr duration)			On	Auto
10	80	50	Auto	Driver fan on	Auto
11	80	50	730	Excursions-Table 3	

In all static condition tests and during the excursions, a constant solar load (730 watts/meter^2) was maintained. On day 2, the vehicle heaters were set on "high." On all other days, the heaters were off.

Days 1 and 10 followed the basic hot scenario, with hours 06:00 to 20:00 as shown on Tables 501.3.II and 505.3-I of MIL-STD-810E (see Table 2). Again, both vehicles were pre-conditioned with the environmental scenario from 24:00 until 06:00. At approximately 06:00, the engines were started and the fans were set to the appropriate setting. Data were collected from 06:00 through 20:00.

During the final day of testing, a number of short excursions were conducted to provide some additional information about heat sources and air flow. For these excursions, additional heat sensors were placed in the engine compartment of each vehicle. One was near the wall across the bulkhead from the driver's right knee; the other sensor was near the bilge pump. A description of the specific excursions is shown in Table 3. At one point during the excursions, the engine doors were opened to visually ensure that the engine fans were turning. The engine fans on both vehicles were turning, albeit fairly slowly.

Table 2. Basic Hot Scenario

Time of day	Ambient air conditions Temp	rH (%)	Induced conditions Temp	rH (%)	Solar radiation (w/m^2)	Btu/ft^2/hr
0100	91	36	91	36		
0200	90	38	90	38		
0300	90	41	90	41	0	0
0400	88	44	88	44		
0500	86	44	86	44		
0600	86	44	88	43	55	18
0700	88	41	93	32		
0800	93	34	100	30		
0900	99	29	108	23	730	231
1000	102	24	113	17		
1100	106	21	124	14		
1200	108	18	135	8	1112	355
1300	109	16	88	6		
1400	109	15	145	6		
1500	109	14	145	5	915	291
1600	109	14	144	6	730	231
1700	109	14	140	6		
1800	108	15	135	6	270	85
1900	104	17	122	10		
2000	100	20	111	14		
2100	97	22	100	19	0	0
2200	95	25	95	25		
2300	93	28	93	28		
2400	91	33	91	33	0	0

Table 3. Schedule of Excursions

Date	Data run	Chamber temp (deg F)	Chamber rH (%)	Solar load	Turret fans	Hull fans
25 Jun 99	23	80	50	730	On, Auto[a]	Both off
25 Jun 99	24	80	50	730	On, Auto[b]	Both off
25 Jun 99	25	80	50	730	On, Auto[a]	Both on
25 Jun 99	26	80	50	730	On, Auto[a]	Both on[d]
25 Jun 99	27	80	50	730	On, Auto[a]	Both off
26 Jun 99	29	80	50	730	All off[c]	Both on

[a]Line-replaceable unit (LRU) circulating fan and commander's exhaust fan only.
[b]LRU circulating fan only
[c]Turret power on; all fans electronically disconnected
[d]Data discarded

3. Results

3.1 Temperature Data

For the test days with static conditions, the average difference between the A2 and A3 at each location is shown in Table 4. Simple T-tests (paired sample) were performed on each pair of A2 and A3 data, grouped by day and sensor location. All differences were significant at well below the .05 confidence level. Actual p values are shown in Appendix B. Plots of the difference between the A2 and A3 for each day at each workstation are shown in Appendix C. All differences are presented in terms of A3-A2, so positive values indicate the A3 was warmer than the A2.

On the day run at 30° F the turret fan in the A3 did not activate at 80° F. When this was noticed, test personnel activated the fan by cycling turret power. In addition, the heater was set on high, but both vehicles stabilized at a temperature at which the crew would have turned the heater off. As a result, the temperatures on the 30° F day should be treated with some care.

The mean temperature data for the two days of solar cycle testing are shown in Figure 1. Again, deltas were derived, based on A3-A2 for each location and fan condition. The delta plots are in Appendix C. Paired T-tests were calculated for each sensor location (see Appendix B), indicating that all differences were significant. The mean and maximum temperatures and differences between the A2 and A3 at each sensor location, with and without the hull fans on, are given in Table 5.

3.2 Smoke Candle Evaluation

Based on observations in the first four days of the evaluation (see conclusions section for an explanation) the chamber operators suggested that, at least when the hull fans were off, warm air was being drawn from the engine compartment into the driver's area of the A3. In order to test this hypothesis, a 15-second plumber's smoke candle was ignited and set in the engine compartment, with the hull fans on and off. When the fans were off, smoke could clearly be seen coming through the holes in the deck at the driver's feet. When the same test was conducted with the hull fans on, almost no smoke was drawn into the driver's compartment. All these tests were conducted at vehicle temperatures above 80° F, so the turret fans in the A3 were activated.

Table 4. Mean Temperatures and Vehicular Differences
After the Vehicles Stabilized at Fixed Temperatures

Condition		A2	A3	Delta	A2	A3	Delta	A2	A3	Delta
30° F, -- percent rH, Solar 730 w/m²: Heater on high										
		Vent fans off								
Driver										
	Head	106.43	121.80	15.38						
	Hand	114.46	126.69	12.23						
	Foot	108.87	136.32	27.45						
Turret										
	Head	93.28	95.14	18.60						
	Hand	102.58	101.54	-1.04						
	Foot	96.97	112.55	15.58						
Squad										
	Head	101.26	107.54	6.27						
	Hand	101.51	105.37	3.86						
	Foot	83.50	75.90	-7.60						
40° F, 50% rH, Solar 730 w/m²										
		Vent fans off								
Driver										
	Head	77.71	89.11	11.40						
	Hand	70.06	78.14	8.08						
	Foot	65.31	73.10	7.79						
Turret										
	Head	70.07	77.83	7.76						
	Hand	68.83	78.61	9.77						
	Foot	68.03	74.48	6.45						
Squad										
	Head	62.28	66.83	4.55						
	Hand	59.83	63.13	3.30						
	Foot	55.64	54.51	-1.13						
80° F, 50% rH, Solar 730w/m²										
		Vent fans off			Vent fans: front on, rear off			Vent fans on		
Driver										
	Head	97.98	123.95	25.97	96.85	104.81	7.96	101.77	103.76	1.99
	Hand	92.96	128.00	35.04	97.74	101.05	3.31	102.36	102.26	-0.10
	Foot	90.16	124.87	34.71	95.14	101.36	6.22	100.72	101.51	0.79
Turret										
	Head	91.07	103.84	12.77	91.01	100.18	9.17	93.62	101.40	7.78
	Hand	91.47	101.69	10.22	92.79	99.52	6.73	93.97	101.23	7.26
	Foot	91.77	107.55	15.78	90.83	100.37	9.54	94.50	102.60	8.10
Squad										
	Head	86.93	104.98	18.05	87.13	93.99	6.86	90.74	95.60	4.86
	Hand	84.56	101.05	16.49	87.04	93.96	6.92	90.83	95.88	5.05
	Foot	80.38	87.91	7.53	84.77	93.63	8.86	90.07	95.60	5.53

Table 4 (continued)

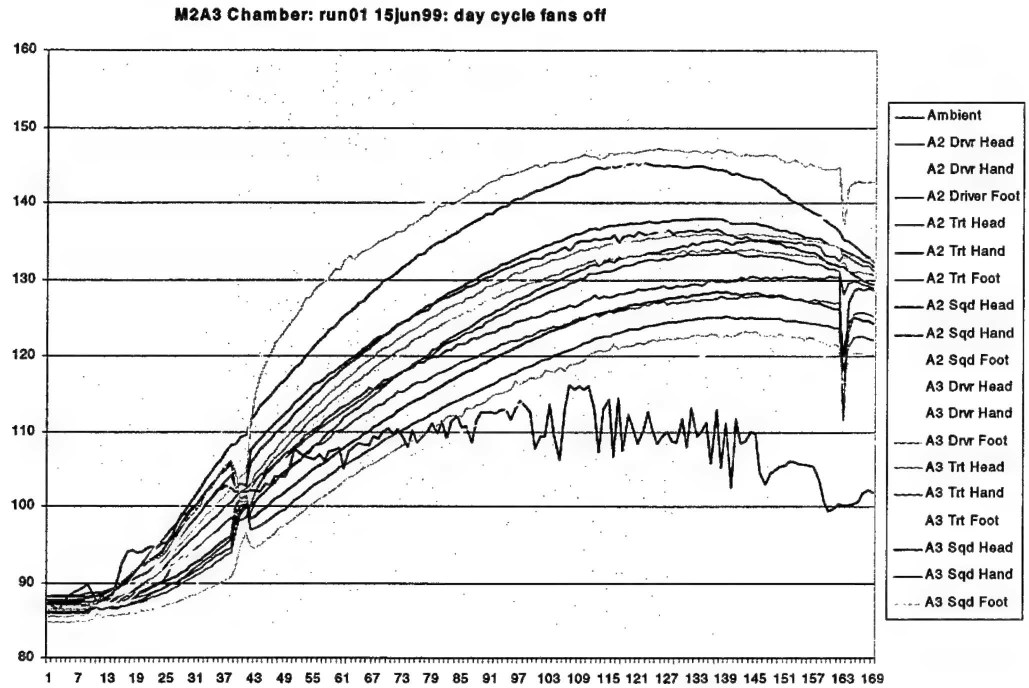
Condition		A2	A3	Delta	A2	A3	Delta	A2	A3	Delta
100° F, 50% rH, Solar 730w/m²										
		Vent fans off			Vent fans: front on, rear off			Vent fans on		
Driver										
	Head	129.35	141.27	11.92				128.44	126.30	-2.14
	Hand	124.10	144.95	20.85				128.67	124.30	-4.37
	Foot	120.63	142.07	21.44				127.57	123.27	-4.30
Turret										
	Head	123.29	127.14	3.85				119.05	124.88	5.84
	Hand	123.58	125.10	1.52				119.19	124.67	5.48
	Foot	122.49	130.20	7.71				119.41	126.86	7.45
Squad										
	Head	115.51	125.49	9.98				115.40	117.93	2.53
	Hand	113.13	122.46	9.32				115.49	118.23	2.74
	Foot	108.89	112.23	3.33				114.65	117.85	3.21
125° F, rH uncontrolled, Solar 730w/m²										
		Vent fans off								
Driver										
	Head	155.07	152.21	-2.87						
	Hand	150.86	155.57	4.71						
	Foot	147.76	153.56	5.80						
Turret										
	Head	149.75	144.69	-5.07						
	Hand	151.24	141.72	-9.52						
	Foot	147.24	145.58	-1.66						
Squad										
	Head	139.61	137.97	-1.64						
	Hand	137.19	136.44	-0.75						
	Foot	133.50	128.60	-4.90						

3.3 Human Performance Calculations

While statistically significant differences are interesting, they do not directly indicate the operational significance of any differences between the A2 and A3. In looking at the effects of temperature and humidity on human performance, the Department of Defense used the WBGT. WBGT is a combination of dry bulb temperature, wet bulb temperature (which includes humidity and air flow), and solar load.

WBGT = (0.7 * wet bulb temp) + (0.2 * black globe temp) + (0.1 * shaded dry bulb temp)

WBGT is included as the standard when one is looking at human susceptibility to heat stress (HQ, DA, DN, AF, 1980).



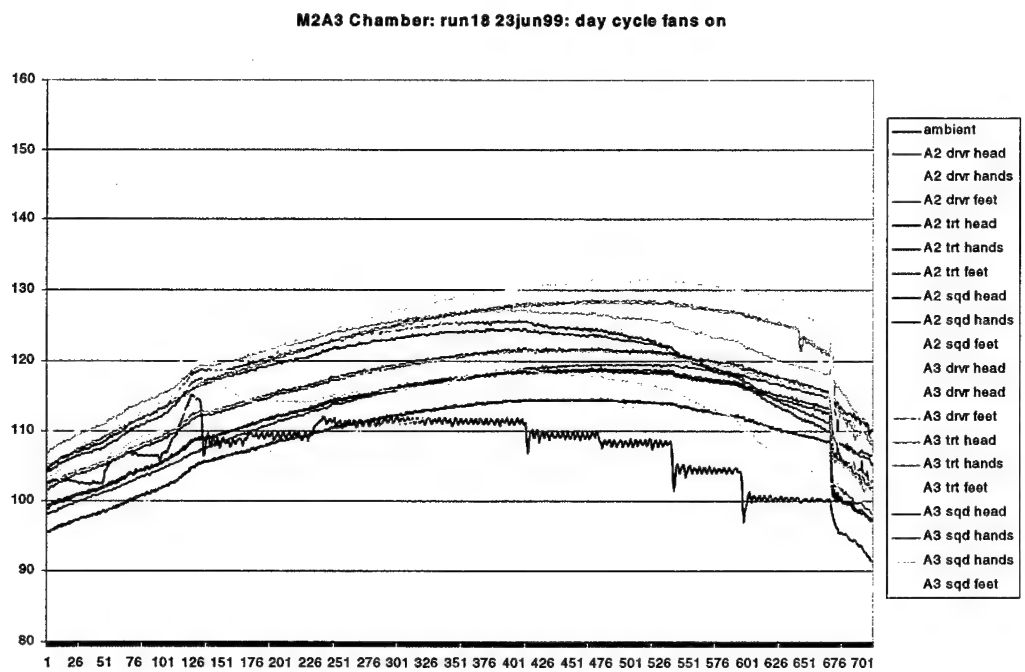


Figure 1. Summary Plots of Temperatures During the "Basic Hot" Scenario.

Table 5. Mean Difference Between A2 and A3 Temperatures
During Basic Hot Scenario

		Fan off			Fan on	
	A2	A3	Delta	A2	A3	Delta
Mean data						
Driver						
Head	126.18	129.44	3.27	113.35	118.32	4.97
Hand	120.18	129.63	9.45	113.91	116.30	2.39
Foot	116.71	128.62	11.91	112.83	115.84	3.11
Turret						
Head	120.53	119.74	-0.79	108.49	116.34	7.84
Hand	121.17	118.53	-2.61	109.08	116.16	7.07
Foot	116.95	118.80	1.85	108.58	117.52	8.95
Squad						
Head	112.52	114.72	2.20	104.81	110.92	6.11
Hand	110.21	112.79	2.58	104.83	111.19	6.36
Foot	106.53	107.93	1.40	104.08	111.17	7.09
Maximum data						
Driver						
Head	145.22	146.35	9.98	125.60	129.90	10.30
Hand	137.78	147.89	18.26	126.00	127.90	7.30
Foot	133.49	147.12	19.83	124.50	127.20	8.90
Turret						
Head	136.51	135.87	3.22	118.60	128.50	14.40
Hand	137.89	133.94	2.00	118.90	128.20	10.10
Foot	135.12	138.45	5.64	119.50	131.20	13.00
Squad						
Head	128.34	130.44	5.71	114.62	121.60	7.59
Hand	125.14	127.83	5.46	114.54	121.73	7.61
Foot	120.57	123.27	3.68	113.50	121.40	8.92

Normally, conversions of dry bulb temperature and relative humidity to WBGT would be done via heat index conversion charts. However, the available charts do not reach many of the temperatures achieved during this study. As a result, conversions to WBGT were done with the El Paso National Weather Service web page calculator (Brice, 1999).

The conversions of the mean temperature data, based on an rH of 50% and an atmospheric pressure of 29.85 inches of Hg are shown in Table 6. The general guideline on thermal stress is that environments should not exceed 85° WBGT whenever possible. As an initial evaluation, Table 6 was inspected for cases when the difference between the A2 and A3 straddled the 85° WBGT criteria.

Table 6. Mean Vehicular Temperatures Converted to WBGT

Condition		Hull vent fan off A2	Hull vent fan off A3	Hull vent fan: front on rear off A2	Hull vent fan: front on rear off A3	Hull vent fan on A2	Hull vent fan on A3
30° F							
Driver	Head	**87.9**	**100.9**				
	Hand	**94.6**	**105.1**				
	Feet	**90.5**	**113.2**				
Turret	Head	76.9	78.5				
	Hand	84.7	83.8				
	Feet	80.0	**92.9**				
Squad	Head	83.6	**88.8**				
	Hand	83.8	**87.0**				
	Feet	68.9	62.4				
40° F							
Driver	Head	64.2	73.5				
	Hand	56.8	64.6				
	Feet	54.0	60.4				
Turret	Head	59.0	64.2				
	Hand	56.8	64.9				
	Feet	56.2	61.5				
Squad	Head	51.5	55.3				
	Hand	49.6	52.2				
	Feet	45.8	45.1				
80° F							
Driver	Head	80.8	**102.6**	79.9	**86.6**	84.0	**85.7**
	Hand	76.7	**106.0**	80.9	83.4	84.5	83.4
	Feet	74.4	**103.4**	78.5	83.6	83.1	83.8
Turret	Head	75.1	**85.9**	75.1	82.7	77.2	83.7
	Hand	75.6	84.0	76.6	82.2	77.5	83.6
	Feet	75.7	**88.8**	74.9	82.9	77.8	84.7
Squad	Head	71.7	**86.7**	71.9	77.6	74.9	78.9
	Hand	69.8	83.8	71.9	77.5	74.9	79.2
	Feet	66.6	72.5	70.0	77.3	74.3	78.9
100° F							
Driver	Head	**107.2**	**117.5**			**106.5**	**104.7**
	Hand	**102.8**	**120.6**			**106.7**	**103.0**
	Feet	**99.8**	**118.2**			**105.7**	**102.1**
Turret	Head	**102.0**	**105.4**			**98.4**	**103.4**
	Hand	**102.3**	**103.6**			**98.6**	**103.3**
	Feet	**101.4**	**108.0**			**98.8**	**105.1**
Squad	Head	**95.5**	**104.0**			**95.4**	**97.6**
	Hand	**93.5**	**101.5**			**95.5**	**98.4**
	Feet	**90.0**	**92.8**			**94.8**	**97.5**
125° F							
Driver	Head	**129.3**	**126.9**				
	Hand	**125.7**	**129.8**				
	Feet	**123.0**	**128.0**				
Turret	Head	**124.8**	**120.4**				
	Hand	**126.0**	**117.9**				
	Feet	**122.6**	**121.0**				
Squad	Head	**116.1**	**114.5**				
	Hand	**114.0**	**113.3**				
	Feet	**110.8**	**106.6**				

Another way of looking these values is to translate them into the maximum time that a crew could function in each environment. Based on the time limits in TB-MED 507 (HQ, DA, DN, AF, 1980) (see Figure 2), the values in Table 6 were converted into maximum time limits for exposure to each environment, assuming a moderate workload. Since values below 85° F WBGT are not time limited for moderate work, they were excluded from Table 7.

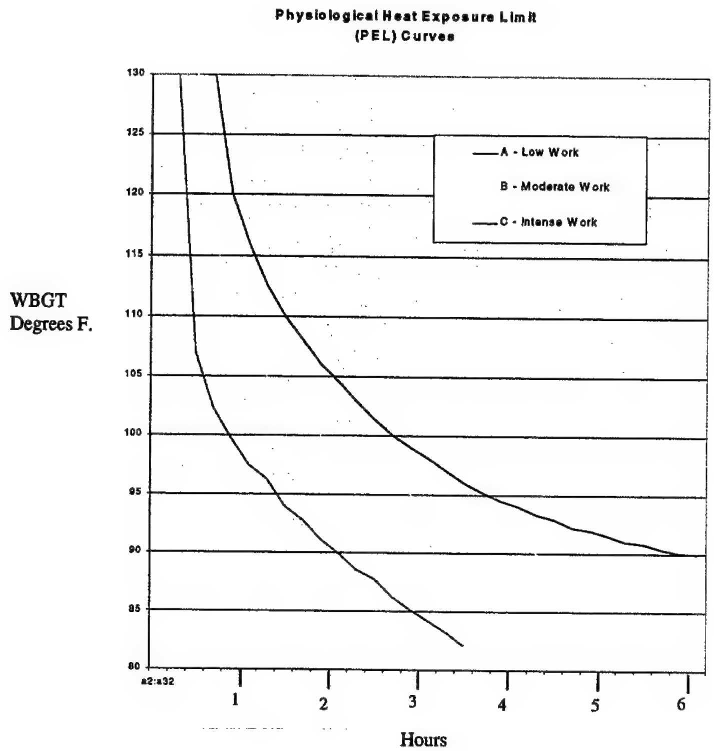


Figure 2. Exposure Limit Curve From TB MED 507.

The time limits are based on soldiers working in normal uniforms. As a rule of thumb, mission-oriented protective posture (MOPP)-4 effectively increases the WBGT by 10° F.

3.4 Excursion Data

The data for the engine sensors from the excursions are plotted in Figure 3. In viewing these plots, it is important to understand that the beginning of the plot includes the engine's prior conditions. For instance, on the first plot, all the sensors start at 80° F, the starting temperature of the vehicle. It is not until about data point 121 (x-axis) that the temperature begins to stabilize, indicating the actual operating temperatures at each location during those conditions.

Table 7. Maximum Exposure Times for Crews During Each Condition

Condition		Hull vent fan off A2	Hull vent fan off A3	Hull vent fan: front on rear off A2	Hull vent fan: front on rear off A3	Hull vent fan on A2	Hull vent fan on A3
30° F							
Driver	Head	4.8	1.7				
	Hand	2.9	1.2				
	Feet	4.0	0.7				
Turret	Head						
	Hand						
	Feet		3.4				
Squad	Head		4.6				
	Hand		5.2				
	Feet						
40° F							
80° F							
Driver	Head		1.5		5.5		6.0
	Hand		1.1				
	Feet		1.4				
Turret	Head		5.8				
	Hand						
	Feet		4.6				
Squad	Head		5.4				
	Hand						
	Feet						
100° F							
Driver	Head	1.0	0.6			1.0	1.2
	Hand	1.5	0.6			1.0	1.4
	Feet	1.8	0.6			1.1	1.5
Turret	Head	1.6	0.6			2.0	1.4
	Hand	1.6	1.4			2.1	1.4
	Feet	1.6	1.0			2.1	1.2
Squad	Head	2.8	0.9			2.7	2.2
	Hand	3.2	1.6			2.7	2.1
	Feet	4.2	3.4			2.8	2.2
125° F							
Driver	Head	0.5*	0.5				
	Hand	0.5	0.5*				
	Feet	0.5	0.5				
Turret	Head	0.5	0.6				
	Hand	0.5	0.6				
	Feet	0.6	0.5				
Squad	Head	0.6	0.7				
	Hand	0.7	0.7				
	Feet	0.8	1.0				

*Values extrapolated beyond the extreme limits of the table.

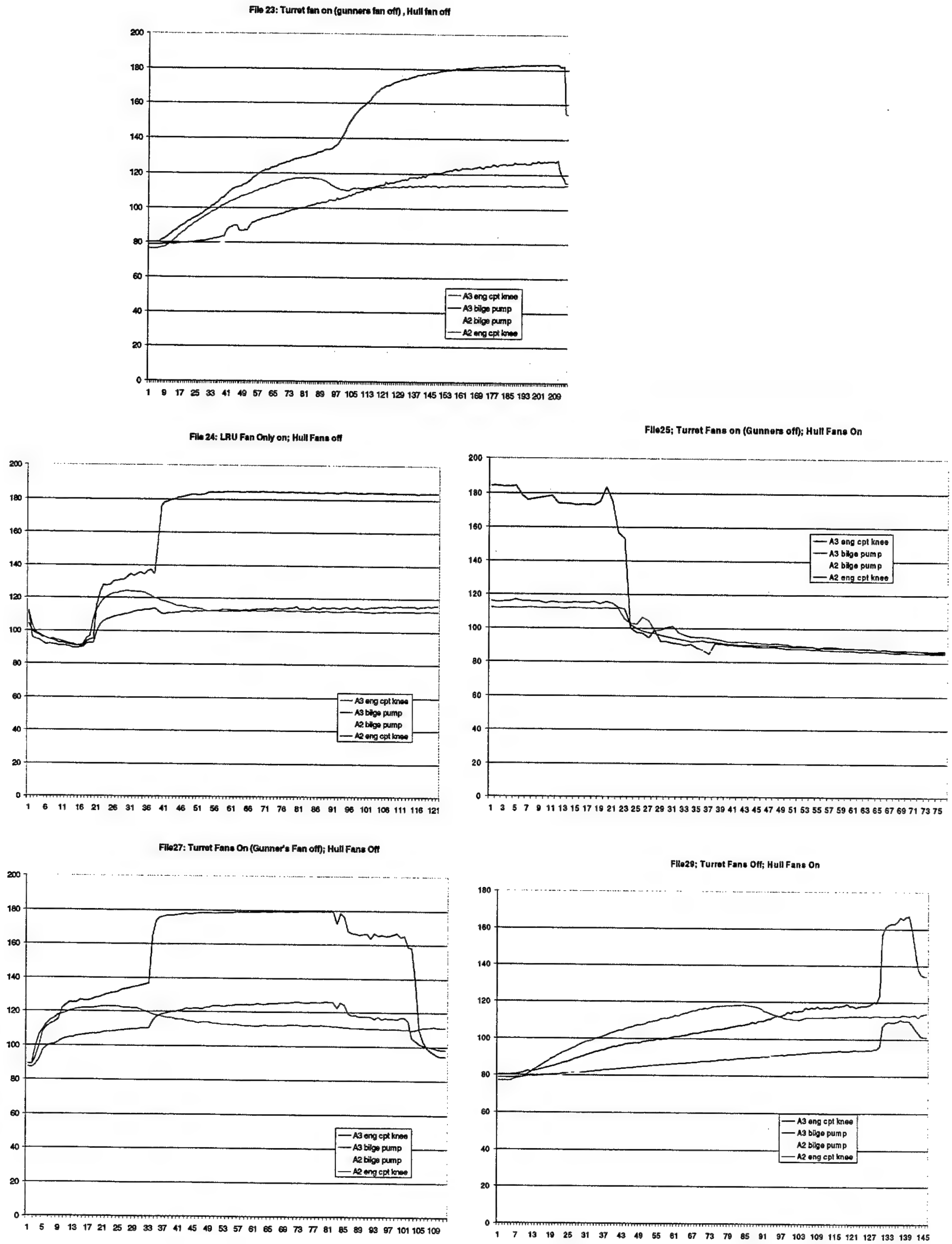


Figure 3. Plots of Temperature Data From Excursions.

The excursions were not part of the originally scheduled test. They were conducted to support the PM Bradley and United Defense Limited Partnership (UDLP) engineers. UDPL may conduct a more detailed analysis of these data in a separate report.

The excursion data do seem to support the findings from the driver's temperature data and the smoke candle trial. In cases when the hull fans were off but the turret fan was on (files 23 and 27), the hot air was drawn from the engine, over the knee sensor in the engine compartment on its way into the driver's compartment. When the hull fans are off but only the line-replaceable unit (LRU) fan is on in the turret (file 24), the LRU appears to still be capable of creating an under-pressure, drawing engine air toward the driver's compartment.

When the turret and hull fans are on (files 25), the temperatures in both vehicles' engine compartments are comparable.

To ensure that the vehicles' engines were operating at the same temperature, a trial (29) with all fans off was conducted. This trial showed that the engine compartment temperatures at each sensor location were similar across vehicles.

4. Conclusions

4.1 Discussion

Based on the results of the tests with the hull vents fans off, which are supported by the smoke test, it is evident that the A3 can become much warmer than the A2, specifically in the driver's compartment. It appears that when the turret fans are activated, at approximately 80° F internal temperature, they create an under-pressure in the crew areas by blowing air out through the back of the turret. Air drawn through the holes at the driver's feet relieves the under-pressure. Since this air has passed through the engine compartment, it is unacceptably warm.

When the hull fans are turned on and the turret fans are on, the overpressure is defeated by the air drawn in by the fans. This was indicated by the lack of smoke coming from the engine compartment into the driver's area when the hull fans were on. The result was that, with the hull fans on, the A3 driver's area was between 1.99° warmer (80° F, head) and 4.37° cooler (100° F, hands) than the comparable A2 sensor. However, with the fans on, the turret temperatures are still between 8.10° (80° F, feet) and 5.48° F (100° F, hands) warmer than in the A2. While this is clearly less of a concern than the temperature differences of more than 10° F seen in all sensors in the driver's compartment with the fans off, it should be re-examined if future changes in the Bradley family include additional automation.

However, in the case of the A2-A3 comparison, the maximum recommended exposure to the temperatures recorded, at least at 100° F, is slightly longer in the A3 than in the A2.

In both vehicles, operations at or below 80° F, 50% rH, should not suffer from crew degradation because of thermal stress. However, operations at 100° F and 125° F will clearly be limited by heat-induced crew degradation. Crews may survive, at least in the 100° F environment, but their ability to function effectively will be severely compromised (Tauson & Doss, 1997). Future improvements in the Bradley family of vehicles should seriously consider addressing this limitation of the system.

4.2 Limitations and Restrictions

There are two restrictions imposed on the design which restrict the ability of the data to be generalized:

1. The heat loads on the vehicles were less than they might be at the same ambient temperature if the engines were run with a load. This is not possible in a chamber environment. Similar restrictions apply to turret movement or other vehicular activities, which might change the heat generation of the vehicle.

2. The readings in the crew compartment did not reflect any effect that a human occupant might cause, in terms of added heat or humidity.

These limitations were not considered critical for this evaluation because the effects should be the same for both vehicles.

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Brice, T. (1999). http://nwselp.epcc.edu/National Weather Service, 7950 Airport Road, Santa Teresa NM 88008 (505) 589-4088

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Headquarters, Departments of the Army, Navy, and Air Force (July 1980). Occupational and environmental health, prevention, treatment, and control (TB MED 507; NAVMED P-5052-5; AFP 160-1).

Tauson, R.A., & Doss, N.W. (1997). The effects of temperature and humidity on squad performance in the proposed U.S. Marine Corps advanced assault amphibious vehicle (ARL-MR-346). Aberdeen Proving Ground, MD: U.S. Army Research Laboratory.

United Defense (1997). BFV A3 electronics ventilation and cooling/A2 temperature baseline test (Technical Report 5233). San Jose, CA: United Defense Limited Partnership.

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APPENDIX A

PHOTOGRAPHS OF SENSOR LOCATIONS

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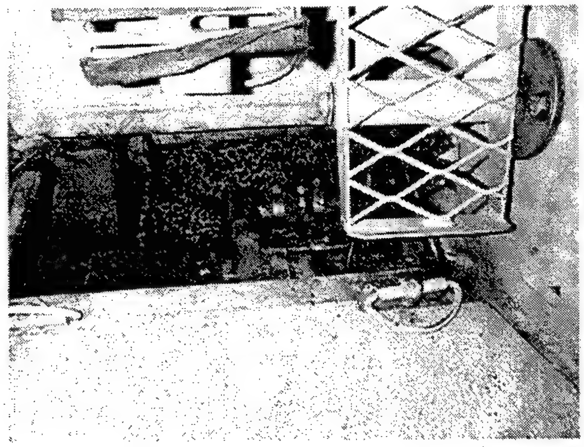

Figure A-1. Photograph of the thermocouple located at the M2A2 bilge pump.

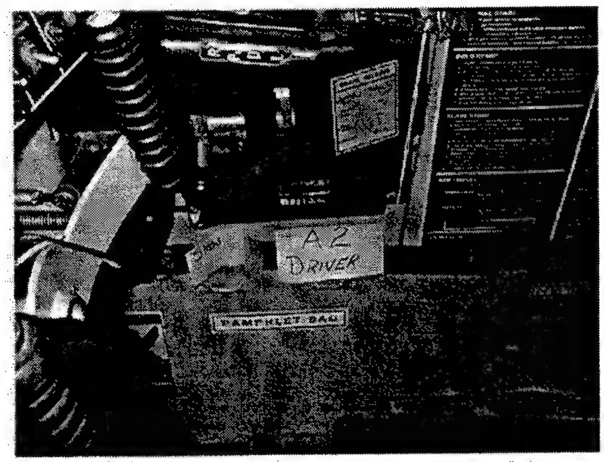

Figure A-2. Photograph of the thermocouple located at the M2A2 bulkhead surface position.

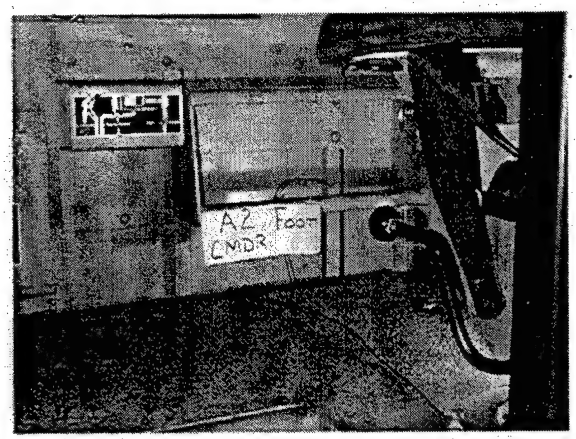

Figure A-3. Photograph of the thermocouple located at the M2A2 commander foot position.

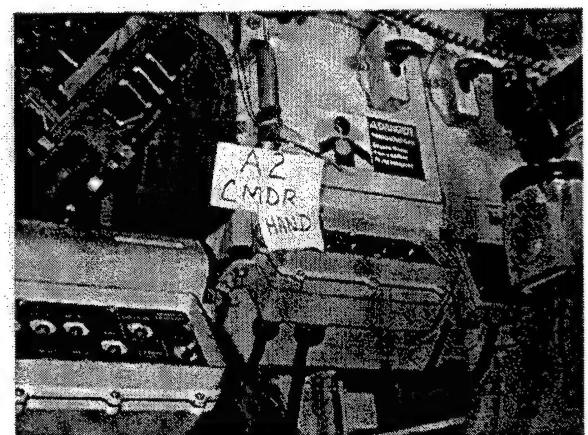

Figure A-4. Photograph of the thermocouple located at the M2A2 commander hand position.

Figure A-5. Photograph of the thermocouple and humidity sensor located at the M2A2 commander head position.

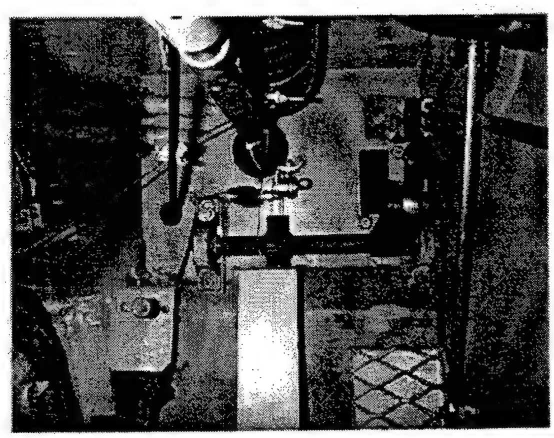

Figure A-6. Photograph of the thermocouple located at the M2A2 driver foot position.

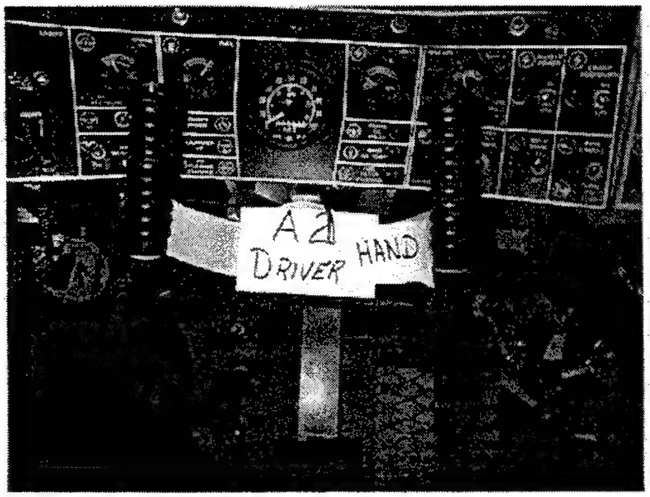

Figure A-7. Photograph of the thermocouple located at the M2A2 Driver hand position.

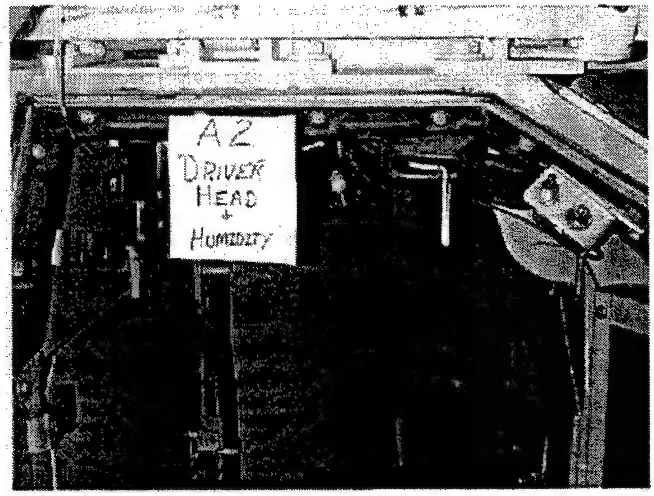

Figure A-8. Photograph of the thermocouple located at the M2A2 Driver head position.

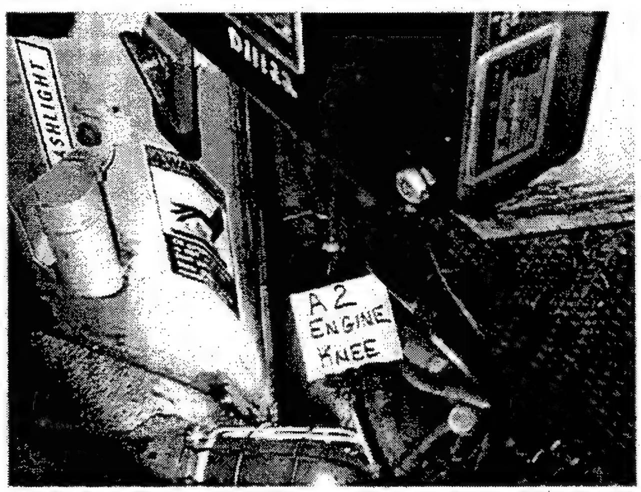

Figure A-9. Photograph of the thermocouple located at the M2A2 engine compartment.

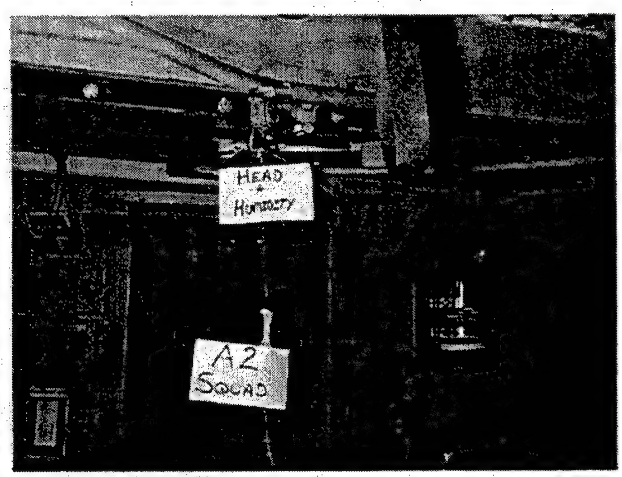

Figure A-10. Photograph of the thermocouple and humidity sensor located at the M2A2 squad area position.

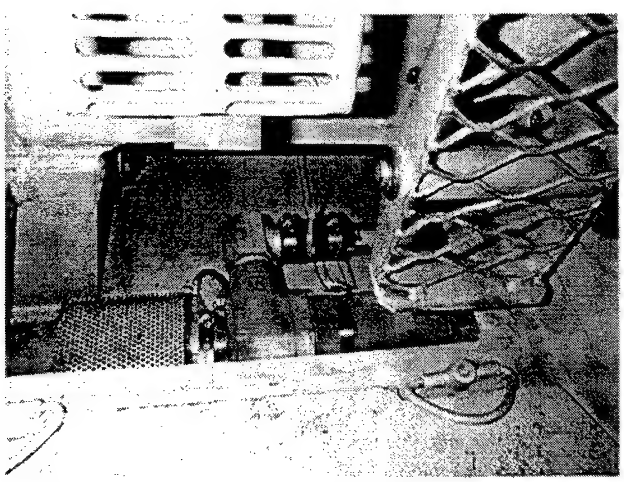

Figure A-11. Photograph of the thermocouple located at the M2A3 bilge pump position.

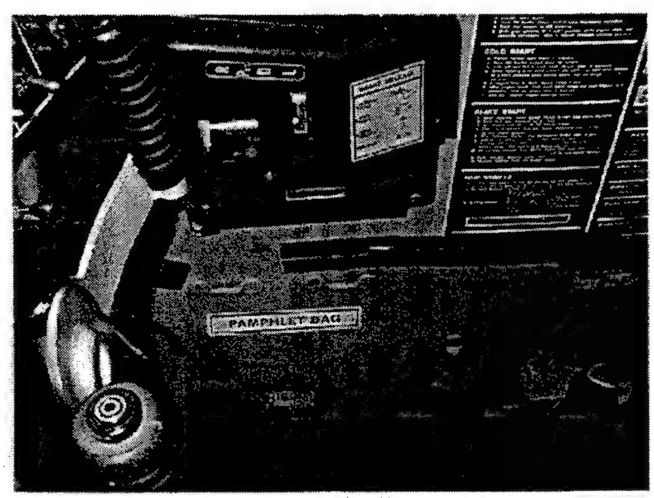

Figure A-12. Photograph of the thermocouple located at the M2A2 bulkhead surface position.

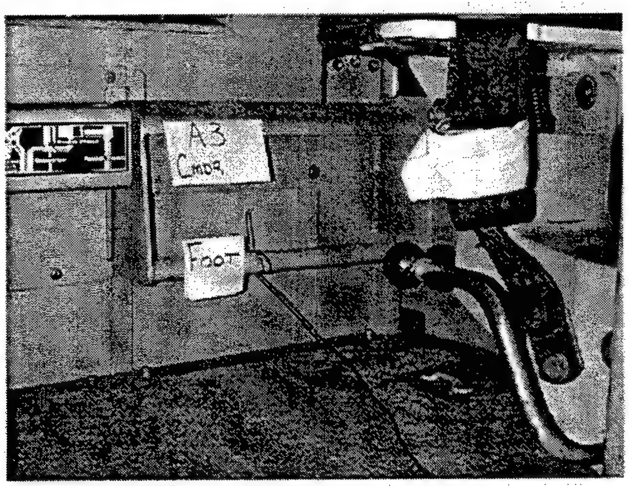

Figure A-13. Photograph of the thermocouple located at the M2A3 commander foot position.

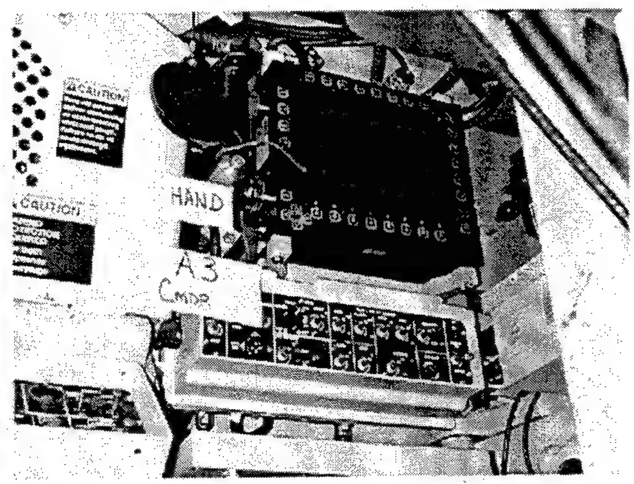

Figure A-14. Photograph of the thermocouple located at the M2A3 commander hand position.

Figure A-15. Photograph of the thermocouple and humidity sensor located at the M2A3 commander head position.

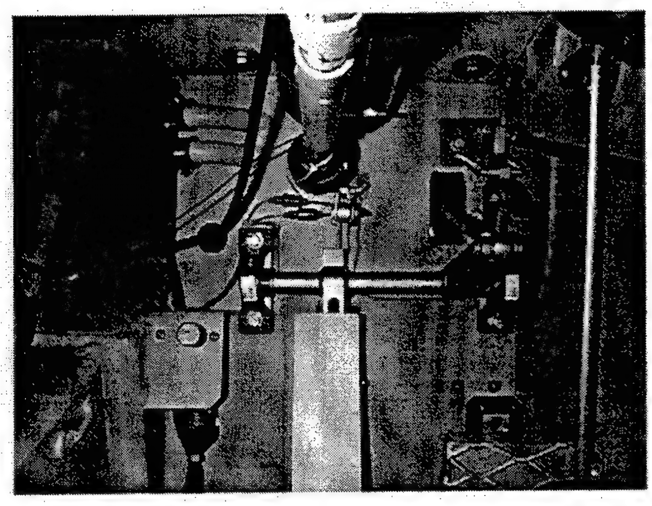

Figure A-16. Photograph of the thermocouple located at the M2A3 driver foot position.

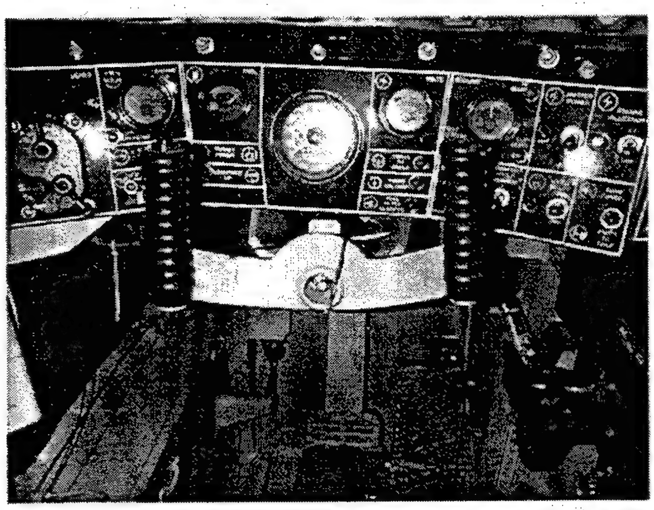

Figure A-17. Photograph of the thermocouple located at the M2A3 driver hand position.

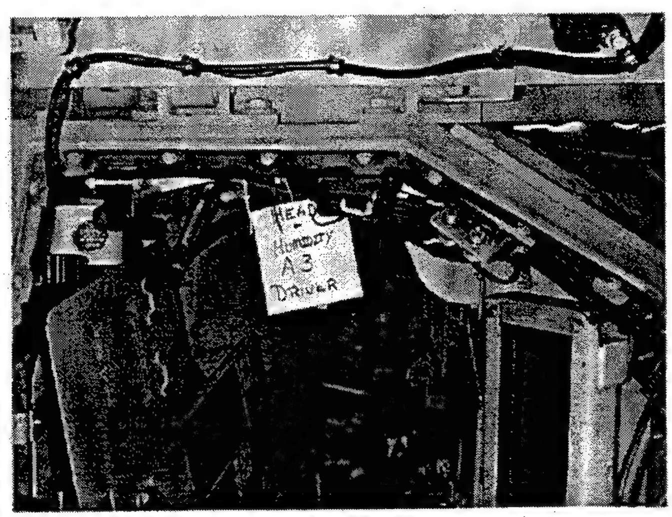

Figure A-18. Photograph of the thermocouple and humidity sensor located at the M2A3 driver head position.

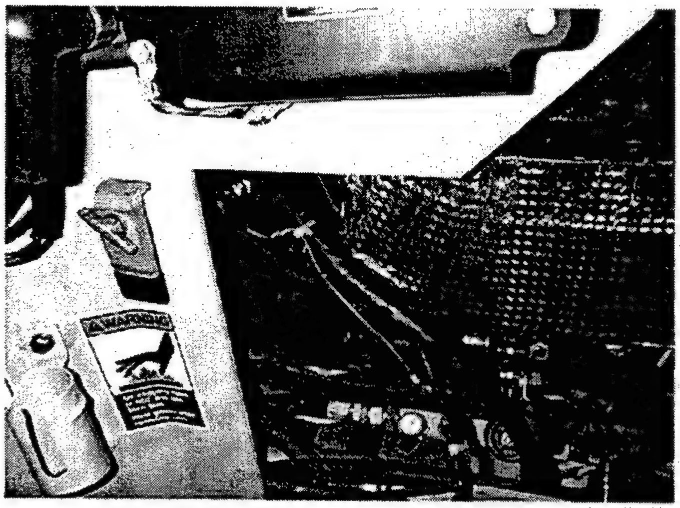

Figure A-19. Photograph of the thermocouple located at the M2A3 engine compartment position.

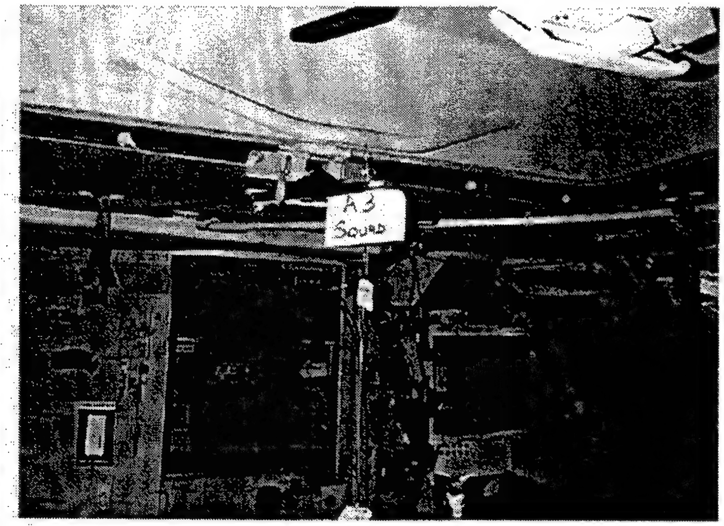

Figure A-20. Photograph of the thermocouple and humidity sensor located at the M2A3 squad area position.

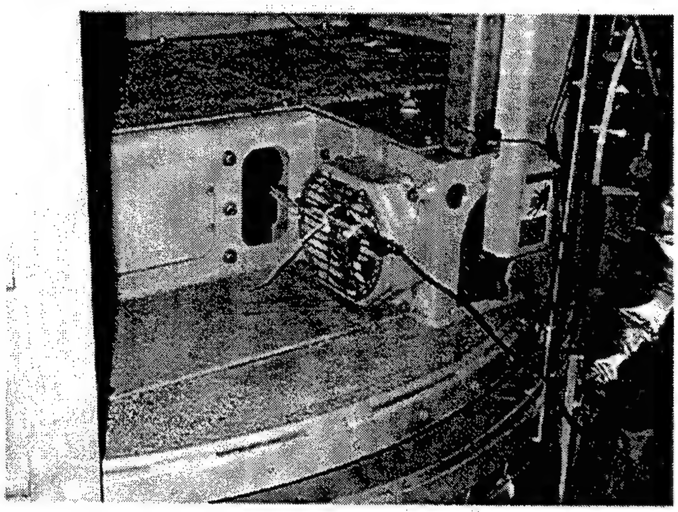

Figure A-21. Photograph of the air velocity sensor located at the M2A3 LRU fan position.

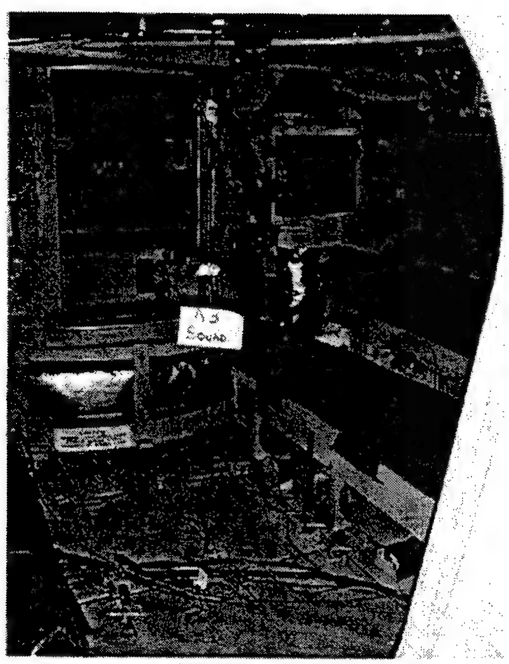

Figure A-22. Photograph of the thermocouple located at the M2A3 squad area position.

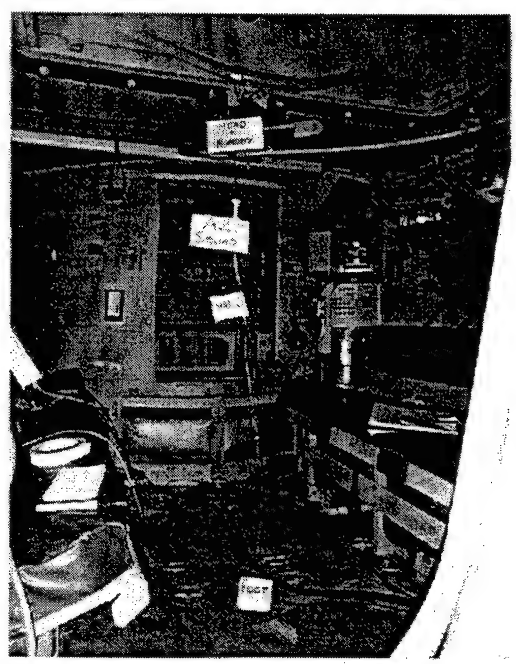

Figure A-23. Photograph of the thermocouple and humidity sensor located at the M2A2 squad position.

APPENDIX B

RESULTS OF T-TESTS FOR TEMPERATURE DATA BETWEEN VEHICLES

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RESULTS OF T-TESTS FOR TEMPERATURE DATA BETWEEN VEHICLES

M2A3 Heat Chamber Test - Day 1 15 June 1999
Diurnal Cycle, Fans Off

Driver Head
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	126.1761	129.4431
Variance	383.8449	422.8947
Observations	169	169
Pearson Correlation	0.991584	
Hypothesized Mean Difference	0	
df	168	
t Stat	-15.2788	
P(T<=t) one-tail	6.69E-34	
t Critical one-tail	1.653975	
P(T<=t) two-tail	1.34E-33	
t Critical two-tail	1.974186	

Driver Hands
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	120.1817	129.6332
Variance	313.6048	479.0883
Observations	169	169
Pearson Correlation	0.974789	
Hypothesized Mean Difference	0	
df	168	
t Stat	-20.1969	
P(T<=t) one-tail	4.14E-47	
t Critical one-tail	1.653975	
P(T<=t) two-tail	8.29E-47	
t Critical two-tail	1.974186	

Driver Feet
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	116.708	128.6191
Variance	264.8261	489.9629
Observations	169	169
Pearson Correlation	0.976858	
Hypothesized Mean Difference	0	
df	168	
t Stat	-21.676	
P(T<=t) one-tail	7.63E-51	
t Critical one-tail	1.653975	
P(T<=t) two-tail	1.53E-50	
t Critical two-tail	1.974186	

Turret Head
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	120.5316	119.7378
Variance	276.115	287.5228
Observations	169	169
Pearson Correlation	0.996215	
Hypothesized Mean Difference	0	
df	168	
t Stat	6.881867	
P(T<=t) one-tail	5.6E-11	
t Critical one-tail	1.653975	
P(T<=t) two-tail	1.12E-10	
t Critical two-tail	1.974186	

Turret Hands
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	121.1733	118.5281
Variance	309.9948	264.0974
Observations	167	167
Pearson Correlation	0.997538	
Hypothesized Mean Difference	0	
df	166	
t Stat	18.97169	
P(T<=t) one-tail	1.01E-43	
t Critical one-tail	1.654084	
P(T<=t) two-tail	2.02E-43	
t Critical two-tail	1.974358	

Turret Feet
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	116.9483	118.8014
Variance	303.7007	350.5215
Observations	169	169
Pearson Correlation	0.99863	
Hypothesized Mean Difference	0	
df	168	
t Stat	-15.0233	
P(T<=t) one-tail	3.46E-33	
t Critical one-tail	1.653975	
P(T<=t) two-tail	6.91E-33	
t Critical two-tail	1.974186	

Squad Head
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	112.5183	114.7177
Variance	218.5436	254.4957
Observations	169	169
Pearson Correlation	0.990909	
Hypothesized Mean Difference	0	
df	168	
t Stat	-12.0223	
P(T<=t) one-tail	1.02E-24	
t Critical one-tail	1.653975	
P(T<=t) two-tail	2.03E-24	
t Critical two-tail	1.974186	

Squad Hands
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	110.2106	112.7928
Variance	191.2983	230.9552
Observations	169	169
Pearson Correlation	0.99226	
Hypothesized Mean Difference	0	
df	168	
t Stat	-14.8356	
P(T<=t) one-tail	1.16E-32	
t Critical one-tail	1.653975	
P(T<=t) two-tail	2.32E-32	
t Critical two-tail	1.974186	

Squad Feet
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	106.5297	107.929
Variance	161.3289	197.5858
Observations	169	169
Pearson Correlation	0.998885	
Hypothesized Mean Difference	0	
df	168	
t Stat	-12.1702	
P(T<=t) one-tail	3.88E-25	
t Critical one-tail	1.653975	
P(T<=t) two-tail	7.75E-25	
t Critical two-tail	1.974186	

File 3; 30F Fans-off, Heater On

Driver Head
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	106.4266	121.8038
Variance	0.377006	0.700313
Observations	120	120
Pearson Correlation	0.847049	
Hypothesized Mean Difference	0	
df	119	
t Stat	-370.385	
P(T<=t) one-tail	2.3E-184	
t Critical one-tail	1.657759	
P(T<=t) two-tail	4.6E-184	
t Critical two-tail	1.980097	

Driver Hands
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	114.4645	126.6921
Variance	0.520741	0.616333
Observations	120	120
Pearson Correlation	0.910537	
Hypothesized Mean Difference	0	
df	119	
t Stat	-412.599	
P(T<=t) one-tail	6.2E-190	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.2E-189	
t Critical two-tail	1.980097	

Driver Feet
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	108.8661	136.321
Variance	0.467194	0.43188
Observations	120	120
Pearson Correlation	0.885141	
Hypothesized Mean Difference	0	
df	119	
t Stat	-933.133	
P(T<=t) one-tail	4.3E-232	
t Critical one-tail	1.657759	
P(T<=t) two-tail	8.5E-232	
t Critical two-tail	1.980097	

Turret Head
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	93.27867	95.13975
Variance	0.503676	0.907698
Observations	120	120
Pearson Correlation	0.365592	
Hypothesized Mean Difference	0	
df	119	
t Stat	-21.29	
P(T<=t) one-tail	1.07E-42	
t Critical one-tail	1.657759	
P(T<=t) two-tail	2.14E-42	
t Critical two-tail	1.980097	

Turret Hands
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	102.579	101.54
Variance	0.588828	1.178894
Observations	120	120
Pearson Correlation	0.181615	
Hypothesized Mean Difference	0	
df	119	
t Stat	9.40316	
P(T<=t) one-tail	2.43E-16	
t Critical one-tail	1.657759	
P(T<=t) two-tail	4.86E-16	
t Critical two-tail	1.980097	

Turret Feet
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	96.969	112.546
Variance	0.70614	0.580328
Observations	120	120
Pearson Correlation	0.42126	
Hypothesized Mean Difference	0	
df	119	
t Stat	-197.413	
P(T<=t) one-tail	6.8E-152	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.4E-151	
t Critical two-tail	1.980097	

Squad Head
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	101.2634	107.5365
Variance	0.361641	3.539688
Observations	120	120
Pearson Correlation	0.863099	
Hypothesized Mean Difference	0	
df	119	
t Stat	-49.2318	
P(T<=t) one-tail	2.83E-81	
t Critical one-tail	1.657759	
P(T<=t) two-tail	5.66E-81	
t Critical two-tail	1.980097	

Squad Hands
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	101.5128	105.3704
Variance	0.295234	4.62094
Observations	120	120
Pearson Correlation	0.951331	
Hypothesized Mean Difference	0	
df	119	
t Stat	-25.7472	
P(T<=t) one-tail	8.9E-51	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.78E-50	
t Critical two-tail	1.980097	

Squad Feet
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	83.49975	75.89908
Variance	0.457794	4.590876
Observations	120	120
Pearson Correlation	0.717275	
Hypothesized Mean Difference	0	
df	119	
t Stat	48.3213	
P(T<=t) one-tail	2.35E-80	
t Critical one-tail	1.657759	
P(T<=t) two-tail	4.7E-80	
t Critical two-tail	1.980097	

M2 Heat Chamber 40F rh 50% vent fans off

Driver Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	77.71308	89.11358
Variance	3.442304	4.439598
Observations	120	120
Pearson Correlation	0.996933	
Hypothesized Mean Difference	0	
df	119	
t Stat	-422.609	
P(T<=t) one-tail	3.6E-191	
t Critical one-tail	1.657759	
P(T<=t) two-tail	7.2E-191	
t Critical two-tail	1.980097	

Driver Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	70.06025	78.14142
Variance	3.398108	4.220254
Observations	120	120
Pearson Correlation	0.99446	
Hypothesized Mean Difference	0	
df	119	
t Stat	-301.079	
P(T<=t) one-tail	1.1E-173	
t Critical one-tail	1.657759	
P(T<=t) two-tail	2.3E-173	
t Critical two-tail	1.980097	

Driver Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	65.31183	73.10425
Variance	3.353697	3.717273
Observations	120	120
Pearson Correlation	0.997936	
Hypothesized Mean Difference	0	
df	119	
t Stat	-551.8	
P(T<=t) one-tail	6E-205	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.2E-204	
t Critical two-tail	1.980097	

Turret Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	70.06892	77.82825
Variance	4.590754	4.967026
Observations	120	120
Pearson Correlation	0.997493	
Hypothesized Mean Difference	0	
df	119	
t Stat	-480.067	
P(T<=t) one-tail	9.3E-198	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.9E-197	
t Critical two-tail	1.980097	

Turret Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	68.8325	78.60717
Variance	4.412553	4.656921
Observations	120	120
Pearson Correlation	0.998046	
Hypothesized Mean Difference	0	
df	119	
t Stat	-738.809	
P(T<=t) one-tail	5E-220	
t Critical one-tail	1.657759	
P(T<=t) two-tail	9.9E-220	
t Critical two-tail	1.980097	

Turret Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	68.03258	74.48108
Variance	3.955172	4.133706
Observations	120	120
Pearson Correlation	0.997786	
Hypothesized Mean Difference	0	
df	119	
t Stat	-501.066	
P(T<=t) one-tail	5.7E-200	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.1E-199	
t Critical two-tail	1.980097	

Squad Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	62.28417	66.83183
Variance	3.289382	3.683539
Observations	120	120
Pearson Correlation	0.995963	
Hypothesized Mean Difference	0	
df	119	
t Stat	-251.433	
P(T<=t) one-tail	2.3E-164	
t Critical one-tail	1.657759	
P(T<=t) two-tail	4.6E-164	
t Critical two-tail	1.980097	

Squad Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	59.83392	63.13158
Variance	2.956258	3.454064
Observations	120	120
Pearson Correlation	0.998062	
Hypothesized Mean Difference	0	
df	119	
t Stat	-202.758	
P(T<=t) one-tail	2.8E-153	
t Critical one-tail	1.657759	
P(T<=t) two-tail	5.7E-153	
t Critical two-tail	1.980097	

Squad Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	55.63883	54.51258
Variance	2.801515	3.280318
Observations	120	120
Pearson Correlation	0.998376	
Hypothesized Mean Difference	0	
df	119	
t Stat	72.79677	
P(T<=t) one-tail	7.9E-101	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.6E-100	
t Critical two-tail	1.980097	

File 7, 80F, fan off

Driver Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	97.9815	123.9492
Variance	0.391583	0.720167
Observations	120	120
Pearson Correlation	0.961756	
Hypothesized Mean Difference	0	
df	119	
t Stat	-946.706	
P(T<=t) one-tail	7.7E-233	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.5E-232	
t Critical two-tail	1.980097	

Driver Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	92.95908	128.0008
Variance	0.327007	0.63084
Observations	120	120
Pearson Correlation	0.968611	
Hypothesized Mean Difference	0	
df	119	
t Stat	-1374.63	
P(T<=t) one-tail	4.1E-252	
t Critical one-tail	1.657759	
P(T<=t) two-tail	8.2E-252	
t Critical two-tail	1.980097	

Drivers Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	90.15817	124.865
Variance	0.277612	0.617252
Observations	120	120
Pearson Correlation	0.92905	
Hypothesized Mean Difference	0	
df	119	
t Stat	-1072.36	
P(T<=t) one-tail	2.8E-239	
t Critical one-tail	1.657759	
P(T<=t) two-tail	5.6E-239	
t Critical two-tail	1.980097	

Turret Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	91.07475	103.835
Variance	0.296106	1.321286
Observations	120	120
Pearson Correlation	0.948699	
Hypothesized Mean Difference	0	
df	119	
t Stat	-213.02	
P(T<=t) one-tail	8.1E-156	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.6E-155	
t Critical two-tail	1.980097	

Turret Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	91.47292	101.6917
Variance	0.29113	1.260098
Observations	120	120
Pearson Correlation	0.96764	
Hypothesized Mean Difference	0	
df	119	
t Stat	-181.817	
P(T<=t) one-tail	1.2E-147	
t Critical one-tail	1.657759	
P(T<=t) two-tail	2.3E-147	
t Critical two-tail	1.980097	

Turret Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	91.76658	107.5525
Variance	0.415791	2.004868
Observations	120	120
Pearson Correlation	0.965625	
Hypothesized Mean Difference	0	
df	119	
t Stat	-213.28	
P(T<=t) one-tail	7E-156	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.4E-155	
t Critical two-tail	1.980097	

Squad Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	86.92917	104.9825
Variance	0.29609	0.849187
Observations	120	120
Pearson Correlation	0.967666	
Hypothesized Mean Difference	0	
df	119	
t Stat	-472.969	
P(T<=t) one-tail	5.5E-197	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.1E-196	
t Critical two-tail	1.980097	

Squad Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	84.56458	101.0517
Variance	0.213023	0.827392
Observations	120	120
Pearson Correlation	0.971102	
Hypothesized Mean Difference	0	
df	119	
t Stat	-380.73	
P(T<=t) one-tail	8.8E-186	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.8E-185	
t Critical two-tail	1.980097	

Squad Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	80.3795	87.91258
Variance	0.104087	0.658324
Observations	120	120
Pearson Correlation	0.961922	
Hypothesized Mean Difference	0	
df	119	
t Stat	-162.209	
P(T<=t) one-tail	8.8E-142	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.8E-141	
t Critical two-tail	1.980097	

File 10, 80F fan on

Driver Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	101.7754	103.761
Variance	0.13839	0.430799
Observations	120	120
Pearson Correlation	0.922069	
Hypothesized Mean Difference	0	
df	119	
t Stat	-63.0771	
P(T<=t) one-tail	1.31E-93	
t Critical one-tail	1.657759	
P(T<=t) two-tail	2.62E-93	
t Critical two-tail	1.980097	

Drivers Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	102.3589	102.2569
Variance	0.191361	0.424237
Observations	120	120
Pearson Correlation	0.973498	
Hypothesized Mean Difference	0	
df	119	
t Stat	4.529616	
P(T<=t) one-tail	7.07E-06	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.41E-05	
t Critical two-tail	1.980097	

Driver Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	100.7229	101.5133
Variance	0.163599	0.423982
Observations	120	120
Pearson Correlation	0.961519	
Hypothesized Mean Difference	0	
df	119	
t Stat	-30.4019	
P(T<=t) one-tail	3.08E-58	
t Critical one-tail	1.657759	
P(T<=t) two-tail	6.16E-58	
t Critical two-tail	1.980097	

Turret Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	93.62417	101.3963
Variance	0.381068	1.095535
Observations	120	120
Pearson Correlation	0.990123	
Hypothesized Mean Difference	0	
df	119	
t Stat	-191.761	
P(T<=t) one-tail	2.1E-150	
t Critical one-tail	1.657759	
P(T<=t) two-tail	4.2E-150	
t Critical two-tail	1.980097	

Turret Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	93.967	101.234
Variance	0.417764	1.093202
Observations	120	120
Pearson Correlation	0.990508	
Hypothesized Mean Difference	0	
df	119	
t Stat	-191.834	
P(T<=t) one-tail	2E-150	
t Critical one-tail	1.657759	
P(T<=t) two-tail	4E-150	
t Critical two-tail	1.980097	

Turret Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	94.49983	102.6033
Variance	0.631089	1.568604
Observations	120	120
Pearson Correlation	0.992562	
Hypothesized Mean Difference	0	
df	119	
t Stat	-187.311	
P(T<=t) one-tail	3.4E-149	
t Critical one-tail	1.657759	
P(T<=t) two-tail	6.9E-149	
t Critical two-tail	1.980097	

Squad Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	90.73533	95.59858
Variance	0.26125	0.550674
Observations	120	120
Pearson Correlation	0.988028	
Hypothesized Mean Difference	0	
df	119	
t Stat	-213.236	
P(T<=t) one-tail	7.2E-156	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.4E-155	
t Critical two-tail	1.980097	

Squad Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	90.82908	95.88375
Variance	0.269761	0.533748
Observations	120	120
Pearson Correlation	0.98749	
Hypothesized Mean Difference	0	
df	119	
t Stat	-238.065	
P(T<=t) one-tail	1.5E-161	
t Critical one-tail	1.657759	
P(T<=t) two-tail	3E-161	
t Critical two-tail	1.980097	

Squad Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	90.06908	95.59625
Variance	0.284587	0.498691
Observations	120	120
Pearson Correlation	0.987347	
Hypothesized Mean Difference	0	
df	119	
t Stat	-305.174	
P(T<=t) one-tail	2.3E-174	
t Critical one-tail	1.657759	
P(T<=t) two-tail	4.6E-174	
t Critical two-tail	1.980097	

M2 Chamber Test, File 14; 21jun99; 100F, 50rH Crew ven fans on

Driver Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	128.435	126.3
Variance	0.443303	0.146891
Observations	120	120
Pearson Correlation	0.960928	
Hypothesized Mean Difference	0	
df	119	
t Stat	74.04262	
P(T<=t) one-tail	1.1E-101	
t Critical one-tail	1.657759	
P(T<=t) two-tail	2.2E-101	
t Critical two-tail	1.980097	

Driver Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	128.6675	124.3017
Variance	0.478851	0.152266
Observations	120	120
Pearson Correlation	0.976774	
Hypothesized Mean Difference	0	
df	119	
t Stat	148.5769	
P(T<=t) one-tail	2.9E-137	
t Critical one-tail	1.657759	
P(T<=t) two-tail	5.7E-137	
t Critical two-tail	1.980097	

Driver Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	127.57	123.2658
Variance	0.436235	0.136386
Observations	120	120
Pearson Correlation	0.97763	
Hypothesized Mean Difference	0	
df	119	
t Stat	152.4162	
P(T<=t) one-tail	1.4E-138	
t Critical one-tail	1.657759	
P(T<=t) two-tail	2.8E-138	
t Critical two-tail	1.980097	

Turret Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	119.045	124.8817
Variance	0.814092	0.445375
Observations	120	120
Pearson Correlation	0.99517	
Hypothesized Mean Difference	0	
df	119	
t Stat	-258.881	
P(T<=t) one-tail	7.1E-166	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.4E-165	
t Critical two-tail	1.980097	

Turret Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	119.19	124.6683
Variance	0.837714	0.461174
Observations	120	120
Pearson Correlation	0.99509	
Hypothesized Mean Difference	0	
df	119	
t Stat	-241.249	
P(T<=t) one-tail	3.1E-162	
t Critical one-tail	1.657759	
P(T<=t) two-tail	6.2E-162	
t Critical two-tail	1.980097	

Turret Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	119.4103	126.8592
Variance	1.1168	0.621596
Observations	120	120
Pearson Correlation	0.996657	
Hypothesized Mean Difference	0	
df	119	
t Stat	-292.928	
P(T<=t) one-tail	3E-172	
t Critical one-tail	1.657759	
P(T<=t) two-tail	6E-172	
t Critical two-tail	1.980097	

Squad Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	115.4042	117.9333
Variance	0.651327	0.271989
Observations	120	120
Pearson Correlation	0.988553	
Hypothesized Mean Difference	0	
df	119	
t Stat	-91.7632	
P(T<=t) one-tail	1.4E-112	
t Critical one-tail	1.657759	
P(T<=t) two-tail	2.8E-112	
t Critical two-tail	1.980097	

Squad Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	115.4913	118.232
Variance	0.662284	0.280633
Observations	120	120
Pearson Correlation	0.991981	
Hypothesized Mean Difference	0	
df	119	
t Stat	-101.434	
P(T<=t) one-tail	1.1E-117	
t Critical one-tail	1.657759	
P(T<=t) two-tail	2.1E-117	
t Critical two-tail	1.980097	

Squad Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	114.6463	117.8525
Variance	0.725852	0.241654
Observations	120	120
Pearson Correlation	0.989222	
Hypothesized Mean Difference	0	
df	119	
t Stat	-94.2383	
P(T<=t) one-tail	6.1E-114	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.2E-113	
t Critical two-tail	1.980097	

M2A3 Chamber Test; file16; 125F fans off

Driver Head
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	155.0725	152.2067
Variance	0.696632	0.055922
Observations	120	120
Pearson Correlation	0.898006	
Hypothesized Mean Difference	0	
df	119	
t Stat	49.75809	
P(T<=t) one-tail	8.46E-82	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.69E-81	
t Critical two-tail	1.980097	

Driver Hands
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	150.8617	155.5675
Variance	0.845745	0.064565
Observations	120	120
Pearson Correlation	0.681483	
Hypothesized Mean Difference	0	
df	119	
t Stat	-67.0092	
P(T<=t) one-tail	1.19E-96	
t Critical one-tail	1.657759	
P(T<=t) two-tail	2.39E-96	
t Critical two-tail	1.980097	

Driver Feet
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	147.7583	153.5625
Variance	1.030014	0.098498
Observations	120	120
Pearson Correlation	0.85328	
Hypothesized Mean Difference	0	
df	119	
t Stat	-83.1332	
P(T<=t) one-tail	1.5E-107	
t Critical one-tail	1.657759	
P(T<=t) two-tail	2.9E-107	
t Critical two-tail	1.980097	

Turret Head
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	149.7508	144.6858
Variance	0.839831	0.149293
Observations	120	120
Pearson Correlation	0.95632	
Hypothesized Mean Difference	0	
df	119	
t Stat	99.35289	
P(T<=t) one-tail	1.2E-116	
t Critical one-tail	1.657759	
P(T<=t) two-tail	2.4E-116	
t Critical two-tail	1.980097	

Turret Hands
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	151.2408	141.7225
Variance	0.930167	0.208313
Observations	120	120
Pearson Correlation	0.96425	
Hypothesized Mean Difference	0	
df	119	
t Stat	193.7624	
P(T<=t) one-tail	6.2E-151	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.2E-150	
t Critical two-tail	1.980097	

Turret Feet
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	147.2392	145.5758
Variance	1.404924	0.553613
Observations	120	120
Pearson Correlation	0.992235	
Hypothesized Mean Difference	0	
df	119	
t Stat	39.91437	
P(T<=t) one-tail	4.75E-71	
t Critical one-tail	1.657759	
P(T<=t) two-tail	9.5E-71	
t Critical two-tail	1.980097	

Squad Head
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	139.6092	137.97
Variance	1.255293	0.156235
Observations	120	120
Pearson Correlation	0.944083	
Hypothesized Mean Difference	0	
df	119	
t Stat	23.67282	
P(T<=t) one-tail	3.86E-47	
t Critical one-tail	1.657759	
P(T<=t) two-tail	7.72E-47	
t Critical two-tail	1.980097	

Squad hands
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	137.1892	136.4425
Variance	1.11173	0.159943
Observations	120	120
Pearson Correlation	0.931354	
Hypothesized Mean Difference	0	
df	119	
t Stat	11.73023	
P(T<=t) one-tail	6.9E-22	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.38E-21	
t Critical two-tail	1.980097	

Squad Feet
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	133.5017	128.6017
Variance	0.896636	0.126552
Observations	120	120
Pearson Correlation	0.95794	
Hypothesized Mean Difference	0	
df	119	
t Stat	87.3267	
P(T<=t) one-tail	4.6E-110	
t Critical one-tail	1.657759	
P(T<=t) two-tail	9.2E-110	
t Critical two-tail	1.980097	

M2 Chamber Test, File 28; 23jun99; Day cycle Crew vent fans on

Driver Head
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	113.3513	118.3234
Variance	139.703	149.7009
Observations	898	898
Pearson Correlation	0.991133	
Hypothesized Mean Difference	0	
df	897	
t Stat	-90.055	
P(T<=t) one-tail	0	
t Critical one-tail	1.646554	
P(T<=t) two-tail	0	
t Critical two-tail	1.962612	

Driver Hands
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	113.9134	116.3021
Variance	140.2205	143.2341
Observations	898	898
Pearson Correlation	0.99575	
Hypothesized Mean Difference	0	
df	897	
t Stat	-64.7893	
P(T<=t) one-tail	0	
t Critical one-tail	1.646554	
P(T<=t) two-tail	0	
t Critical two-tail	1.962612	

Driver Feet
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	112.8313	115.9389
Variance	133.7048	138.4278
Observations	898	898
Pearson Correlation	0.993884	
Hypothesized Mean Difference	0	
df	897	
t Stat	-71.3157	
P(T<=t) one-tail	0	
t Critical one-tail	1.646554	
P(T<=t) two-tail	0	
t Critical two-tail	1.962612	

Turret Head
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	108.494	116.3364
Variance	96.37408	147.6045
Observations	898	898
Pearson Correlation	0.998433	
Hypothesized Mean Difference	0	
df	897	
t Stat	-97.4725	
P(T<=t) one-tail	0	
t Critical one-tail	1.646554	
P(T<=t) two-tail	0	
t Critical two-tail	1.962612	

Turret Hands
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	109.0816	116.1557
Variance	94.16088	145.6585
Observations	898	898
Pearson Correlation	0.9877	
Hypothesized Mean Difference	0	
df	897	
t Stat	-72.8159	
P(T<=t) one-tail	0	
t Critical one-tail	1.646554	
P(T<=t) two-tail	0	
t Critical two-tail	1.962612	

Turret Feet
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	108.5773	117.5246
Variance	108.144	181.7854
Observations	898	898
Pearson Correlation	0.993061	
Hypothesized Mean Difference	0	
df	897	
t Stat	-79.2224	
P(T<=t) one-tail	0	
t Critical one-tail	1.646554	
P(T<=t) two-tail	0	
t Critical two-tail	1.962612	

Squad Head
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	104.8068	110.9199
Variance	88.63686	113.1953
Observations	898	898
Pearson Correlation	0.992589	
Hypothesized Mean Difference	0	
df	897	
t Stat	-106.042	
P(T<=t) one-tail	0	
t Critical one-tail	1.646554	
P(T<=t) two-tail	0	
t Critical two-tail	1.962612	

Squad Hands
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	104.8287	111.1919
Variance	88.19154	111.1179
Observations	898	898
Pearson Correlation	0.993813	
Hypothesized Mean Difference	0	
df	897	
t Stat	-119.461	
P(T<=t) one-tail	0	
t Critical one-tail	1.646554	
P(T<=t) two-tail	0	
t Critical two-tail	1.962612	

Squad Feet
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	104.0764	111.1661
Variance	83.70937	106.826
Observations	898	898
Pearson Correlation	0.993379	
Hypothesized Mean Difference	0	
df	897	
t Stat	-130.27	
P(T<=t) one-tail	0	
t Critical one-tail	1.646554	
P(T<=t) two-tail	0	
t Critical two-tail	1.962612	

File 20, 80F Front Fan only on

Driver Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	96.85342	104.8083
Variance	0.31707	0.421611
Observations	120	120
Pearson Correlation	0.804259	
Hypothesized Mean Difference	0	
df	119	
t Stat	-224.573	
P(T<=t) one-tail	1.5E-158	
t Critical one-tail	1.657759	
P(T<=t) two-tail	3.1E-158	
t Critical two-tail	1.980097	

Driver Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	97.74075	101.0533
Variance	0.352852	0.49814
Observations	120	120
Pearson Correlation	0.972972	
Hypothesized Mean Difference	0	
df	119	
t Stat	-193.531	
P(T<=t) one-tail	7.1E-151	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.4E-150	
t Critical two-tail	1.980097	

Driver Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	95.14375	101.3625
Variance	0.323256	0.543372
Observations	120	120
Pearson Correlation	0.989203	
Hypothesized Mean Difference	0	
df	119	
t Stat	-351.927	
P(T<=t) one-tail	1E-181	
t Critical one-tail	1.657759	
P(T<=t) two-tail	2E-181	
t Critical two-tail	1.980097	

Turret Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	91.01158	100.1833
Variance	0.746765	1.188964
Observations	120	120
Pearson Correlation	0.992944	
Hypothesized Mean Difference	0	
df	119	
t Stat	-395.662	
P(T<=t) one-tail	9E-188	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.8E-187	
t Critical two-tail	1.980097	

Turret Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	92.7925	99.525
Variance	1.121511	1.111471
Observations	120	120
Pearson Correlation	0.988051	
Hypothesized Mean Difference	0	
df	119	
t Stat	-451.309	
P(T<=t) one-tail	1.4E-194	
t Critical one-tail	1.657759	
P(T<=t) two-tail	2.9E-194	
t Critical two-tail	1.980097	

Turret Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	90.825	100.3708
Variance	0.717928	1.304772
Observations	120	120
Pearson Correlation	0.992085	
Hypothesized Mean Difference	0	
df	119	
t Stat	-326.904	
P(T<=t) one-tail	6.5E-178	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.3E-177	
t Critical two-tail	1.980097	

Squad Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	87.13458	93.98567
Variance	0.354284	0.415593
Observations	120	120
Pearson Correlation	0.994902	
Hypothesized Mean Difference	0	
df	119	
t Stat	-941.243	
P(T<=t) one-tail	1.5E-232	
t Critical one-tail	1.657759	
P(T<=t) two-tail	3.1E-232	
t Critical two-tail	1.980097	

Squad Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	87.0425	93.95642
Variance	0.372192	0.41048
Observations	120	120
Pearson Correlation	0.993873	
Hypothesized Mean Difference	0	
df	119	
t Stat	-1000.85	
P(T<=t) one-tail	1E-235	
t Critical one-tail	1.657759	
P(T<=t) two-tail	2E-235	
t Critical two-tail	1.980097	

Squad Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	84.77192	93.63208
Variance	0.404431	0.405269
Observations	120	120
Pearson Correlation	0.994033	
Hypothesized Mean Difference	0	
df	119	
t Stat	-1396.28	
P(T<=t) one-tail	6.4E-253	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.3E-252	
t Critical two-tail	1.980097	

File 12, 100F fans off

Driver Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	129.345	141.265
Variance	1.553756	0.630361
Observations	120	120
Pearson Correlation	0.98989	
Hypothesized Mean Difference	0	
df	119	
t Stat	-275.399	
P(T<=t) one-tail	4.6E-169	
t Critical one-tail	1.657759	
P(T<=t) two-tail	9.2E-169	
t Critical two-tail	1.980097	

Driver Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	124.095	144.9492
Variance	1.673252	0.444705
Observations	120	120
Pearson Correlation	0.988197	
Hypothesized Mean Difference	0	
df	119	
t Stat	-355.435	
P(T<=t) one-tail	3.1E-182	
t Critical one-tail	1.657759	
P(T<=t) two-tail	6.2E-182	
t Critical two-tail	1.980097	

Driver Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	120.6258	142.07
Variance	1.66126	0.411697
Observations	120	120
Pearson Correlation	0.939129	
Hypothesized Mean Difference	0	
df	119	
t Stat	-325.876	
P(T<=t) one-tail	9.4E-178	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.9E-177	
t Critical two-tail	1.980097	

Turret Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	123.2867	127.1375
Variance	1.516291	0.963036
Observations	120	120
Pearson Correlation	0.991932	
Hypothesized Mean Difference	0	
df	119	
t Stat	-147.298	
P(T<=t) one-tail	8E-137	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.6E-136	
t Critical two-tail	1.980097	

Turret Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	123.5775	125.1017
Variance	1.773187	0.911258
Observations	120	120
Pearson Correlation	0.993239	
Hypothesized Mean Difference	0	
df	119	
t Stat	-41.8291	
P(T<=t) one-tail	2.6E-73	
t Critical one-tail	1.657759	
P(T<=t) two-tail	5.2E-73	
t Critical two-tail	1.980097	

Turret Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	122.49	130.2008
Variance	2.118387	1.393529
Observations	120	120
Pearson Correlation	0.995703	
Hypothesized Mean Difference	0	
df	119	
t Stat	-280.958	
P(T<=t) one-tail	4.3E-170	
t Critical one-tail	1.657759	
P(T<=t) two-tail	8.5E-170	
t Critical two-tail	1.980097	

Squad Head
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	115.505	125.485
Variance	1.544176	0.714563
Observations	120	120
Pearson Correlation	0.970459	
Hypothesized Mean Difference	0	
df	119	
t Stat	-233.118	
P(T<=t) one-tail	1.8E-160	
t Critical one-tail	1.657759	
P(T<=t) two-tail	3.6E-160	
t Critical two-tail	1.980097	

Squad Hands
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	113.1342	122.455
Variance	1.383949	0.724513
Observations	120	120
Pearson Correlation	0.978807	
Hypothesized Mean Difference	0	
df	119	
t Stat	-265.213	
P(T<=t) one-tail	4E-167	
t Critical one-tail	1.657759	
P(T<=t) two-tail	8.1E-167	
t Critical two-tail	1.980097	

Squad Feet
t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	108.8942	112.2267
Variance	1.212151	0.681132
Observations	120	120
Pearson Correlation	0.991862	
Hypothesized Mean Difference	0	
df	119	
t Stat	-121.159	
P(T<=t) one-tail	8.5E-127	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.7E-126	
t Critical two-tail	1.980097	

APPENDIX C

PLOTS OF TEMPERATURE DATA

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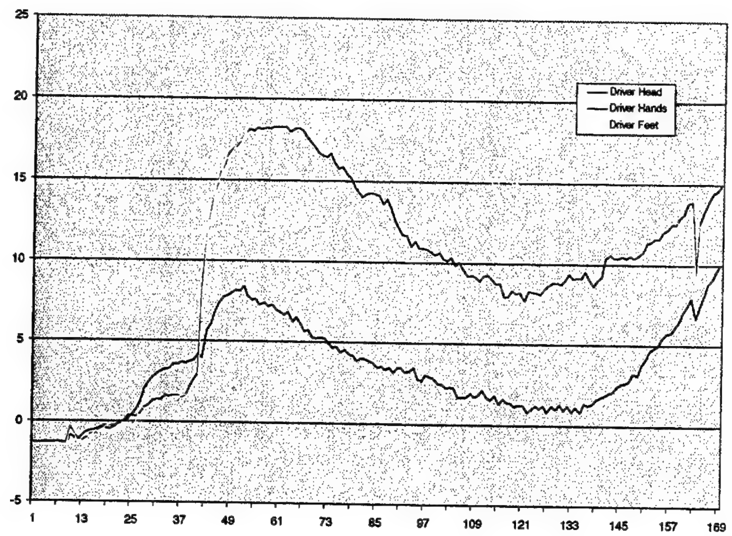
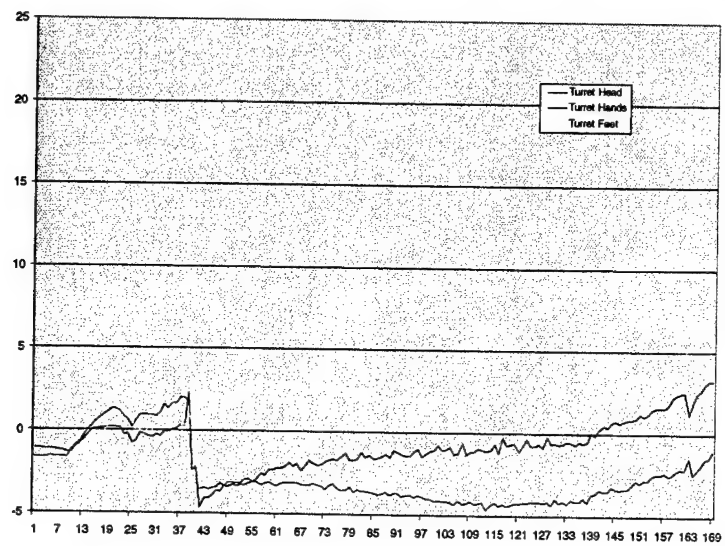
M2A3 Heat Chamber Day Cycle (A3-A2 Deltas) : vent fans off

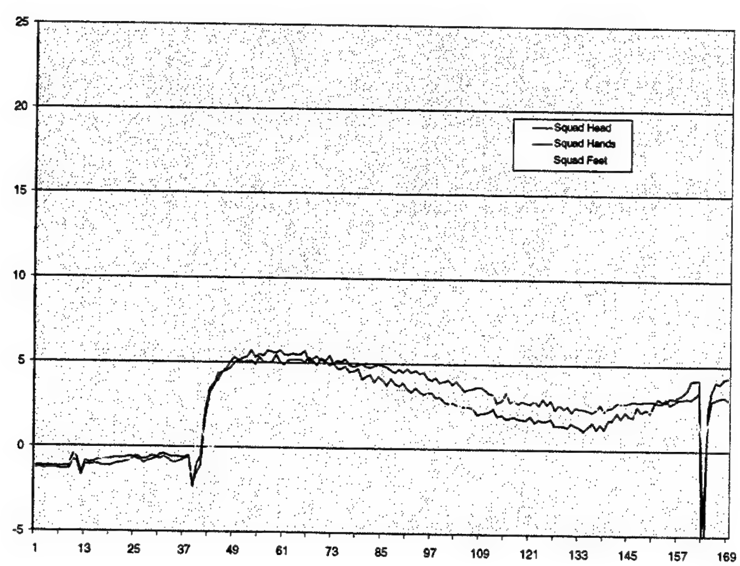
Driver



Turret

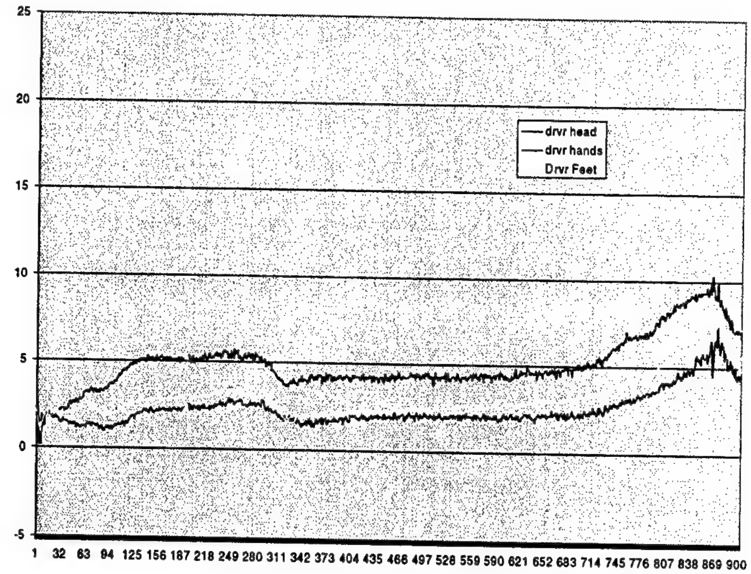


Squad

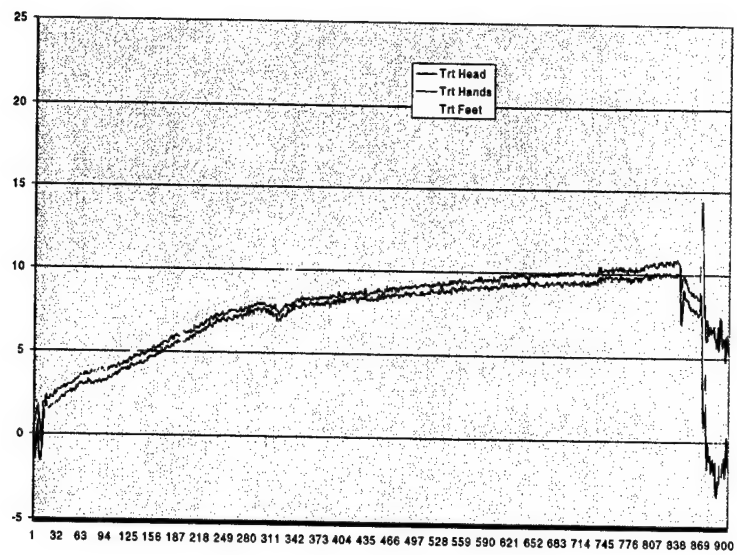


M2A3 Heat Chamber Day Cycle (A3-A2 Deltas) : vent fans on

Driver



Turret



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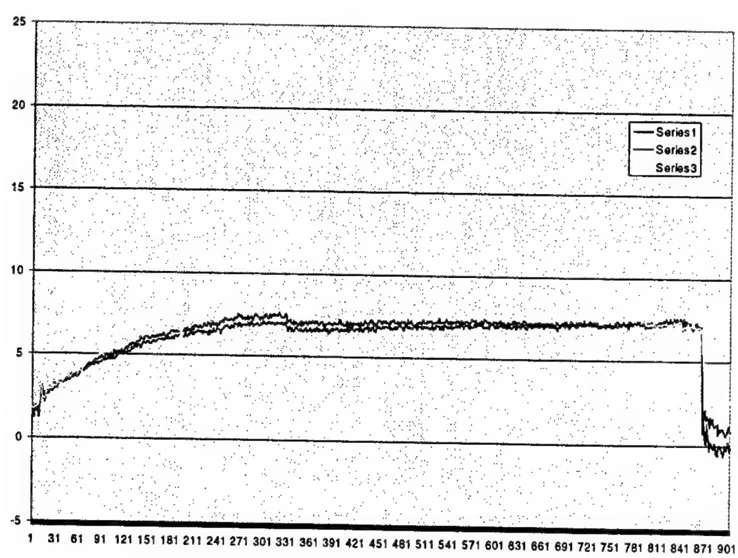
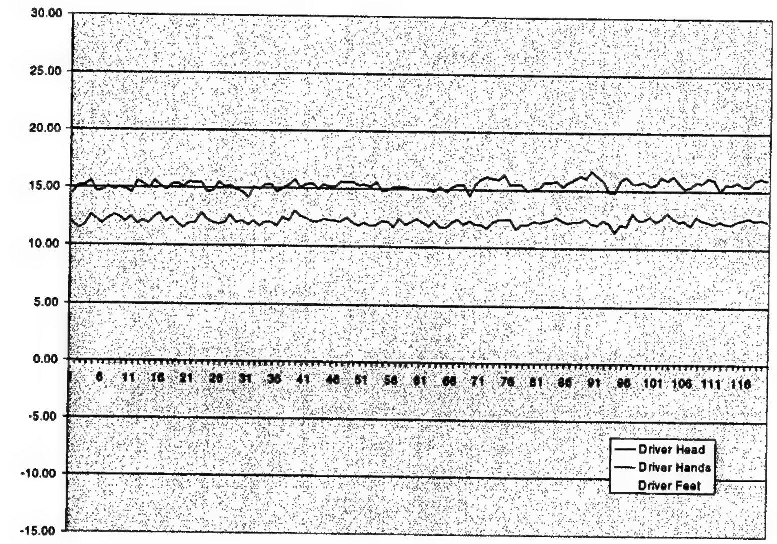
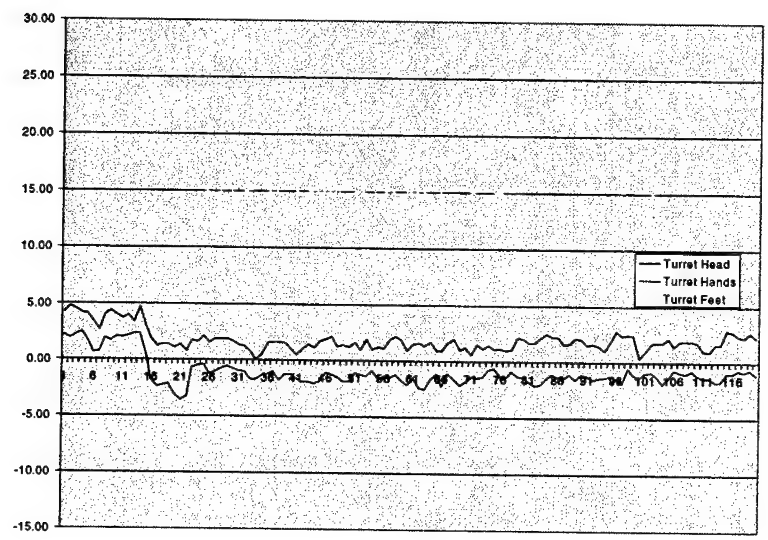


M2A3 Heat Chamber 30F rh 50% vent fans off, Heater on

Driver



Turret



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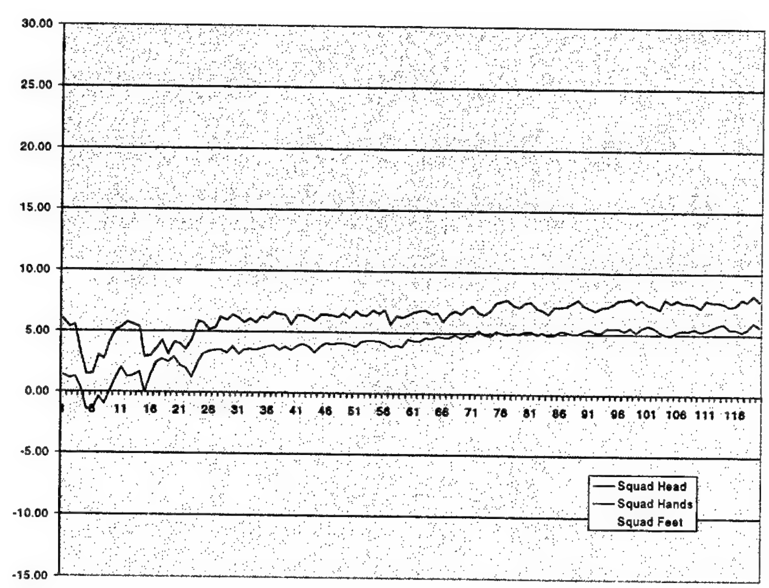
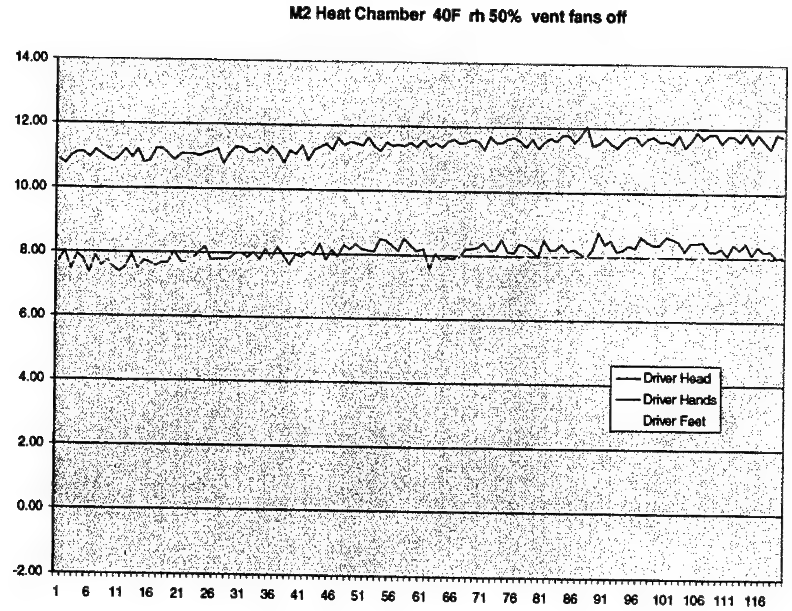
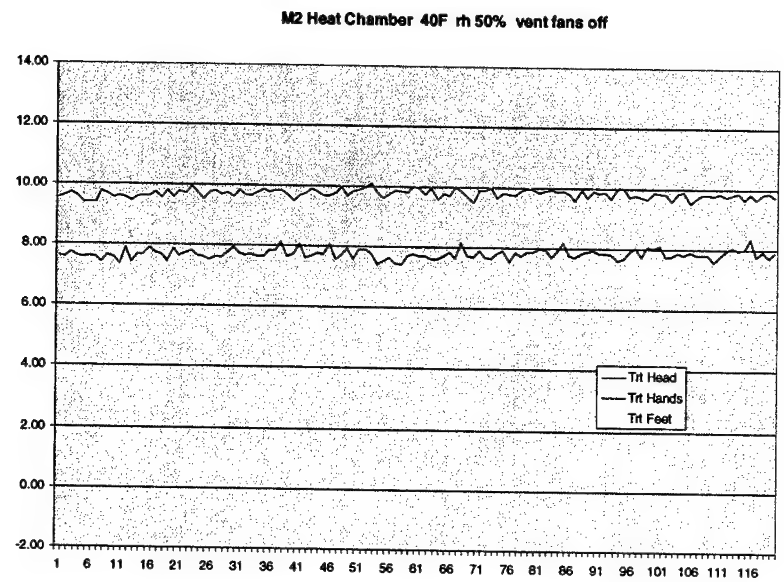


M2A3 Heat Chamber 40° F rh 50% vent fans off

Driver



Turret



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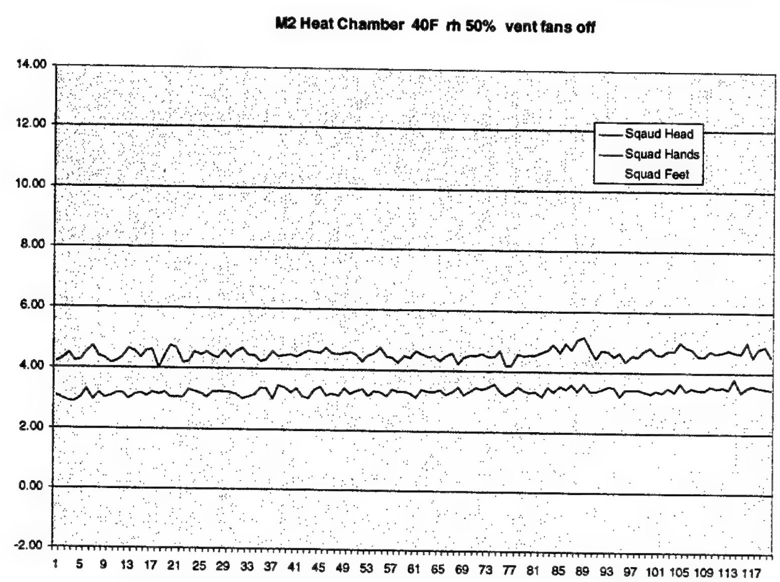
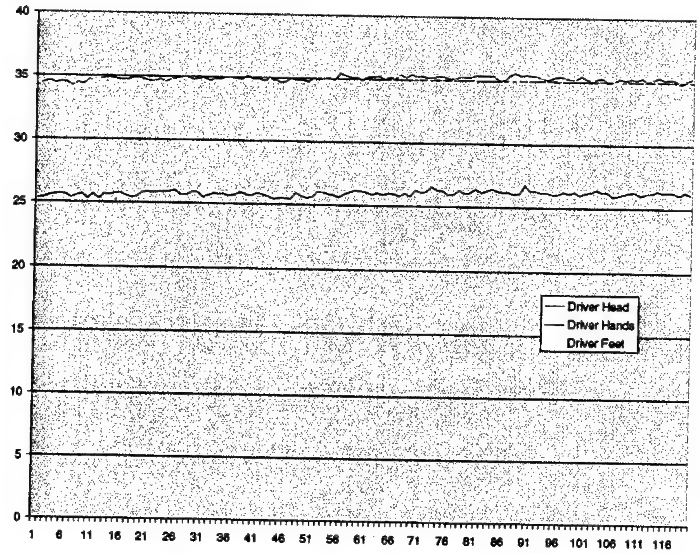
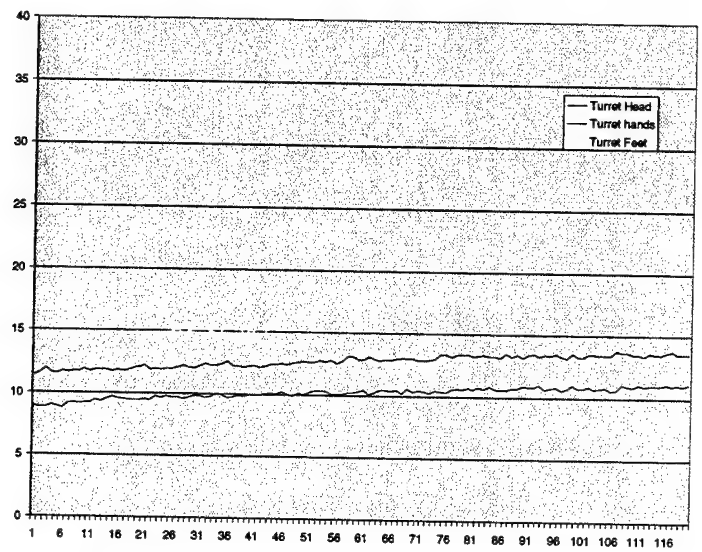


M2A3 Heat Chamber (A3-A2 Deltas) 80°, fans off

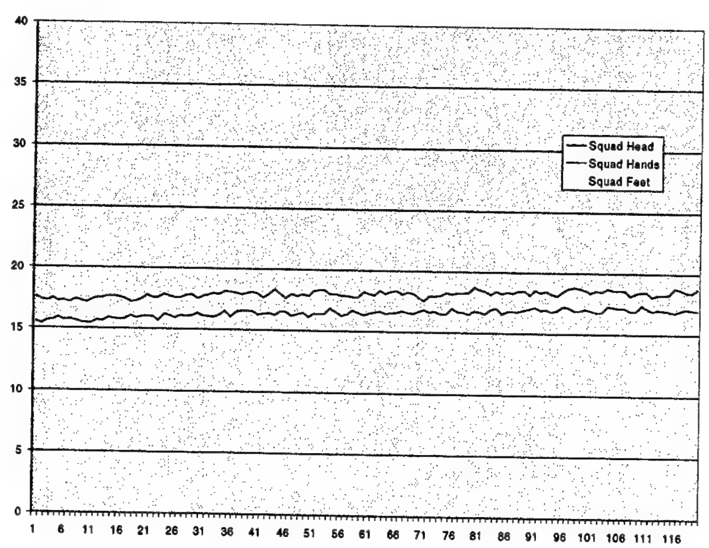
Driver



Turret

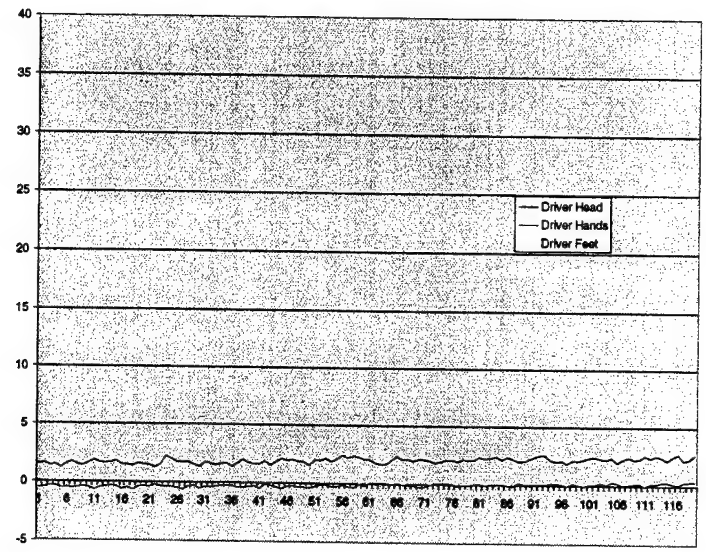


Squad

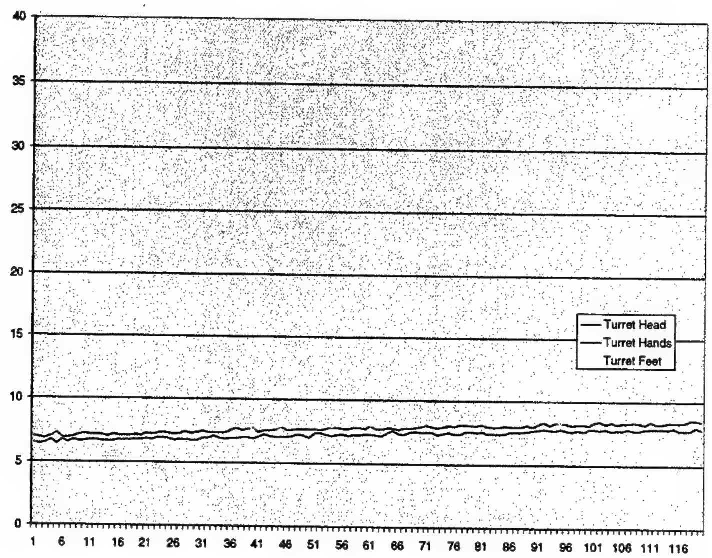


M2A3 Heat Chamber (A3-A2 Deltas) 80°, fans on

Driver



Turret



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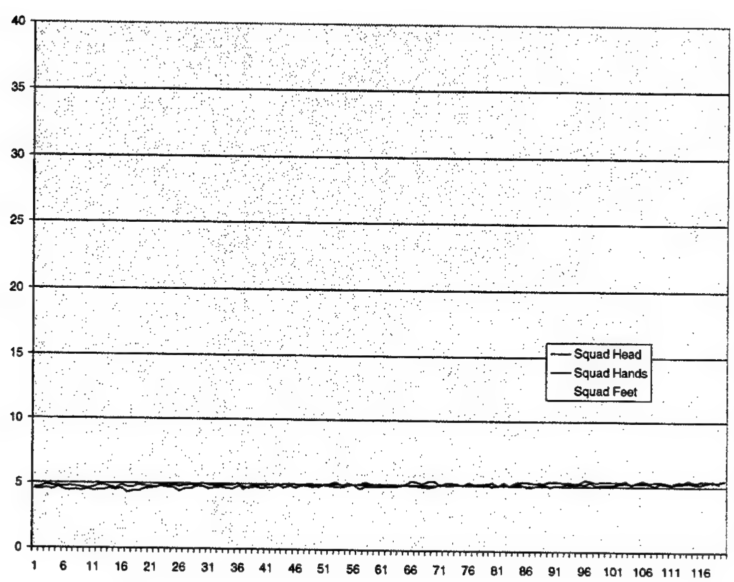
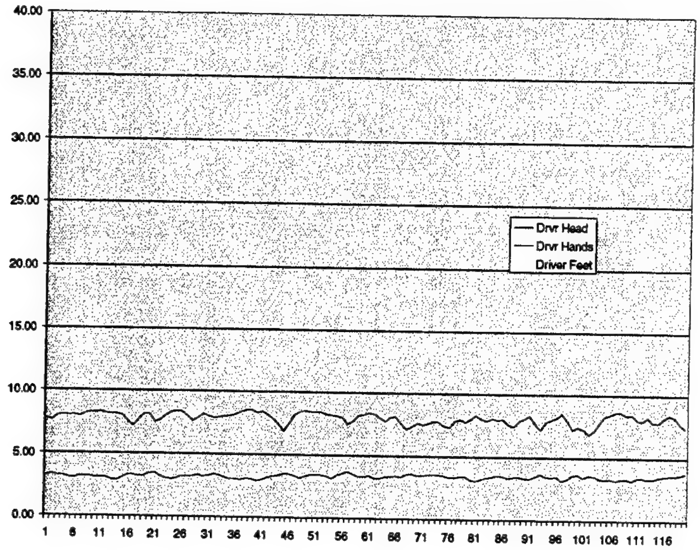
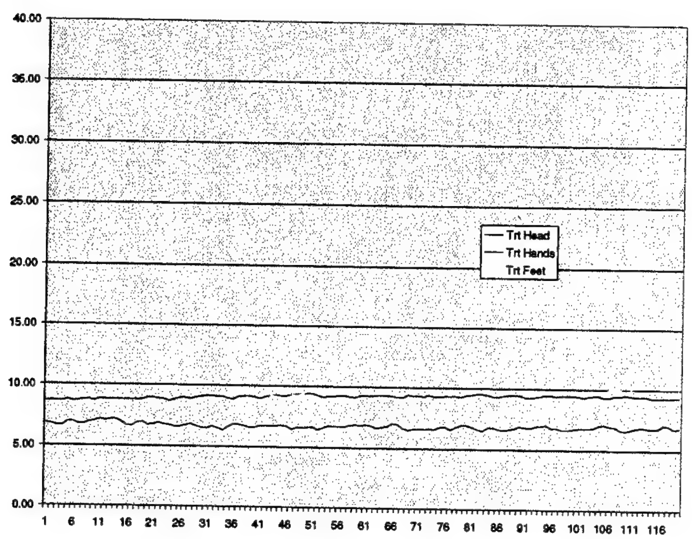


M2A3 Heat Chamber (A3-A2 Deltas) 80° F, 50rH Crew vent fans: front on, rear off

Driver



Turret



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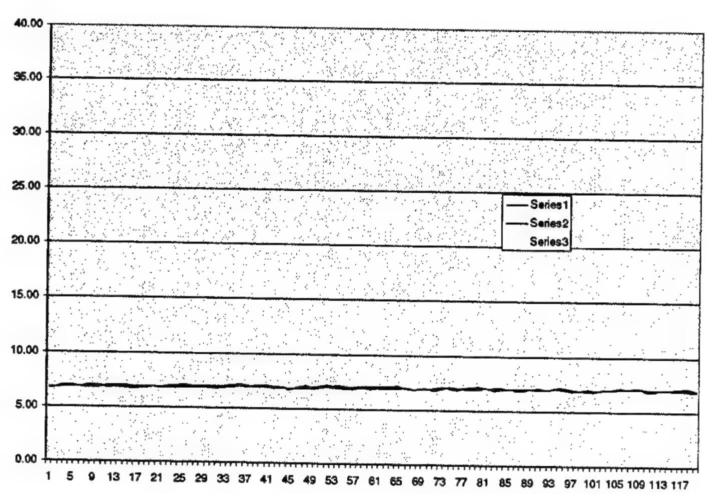
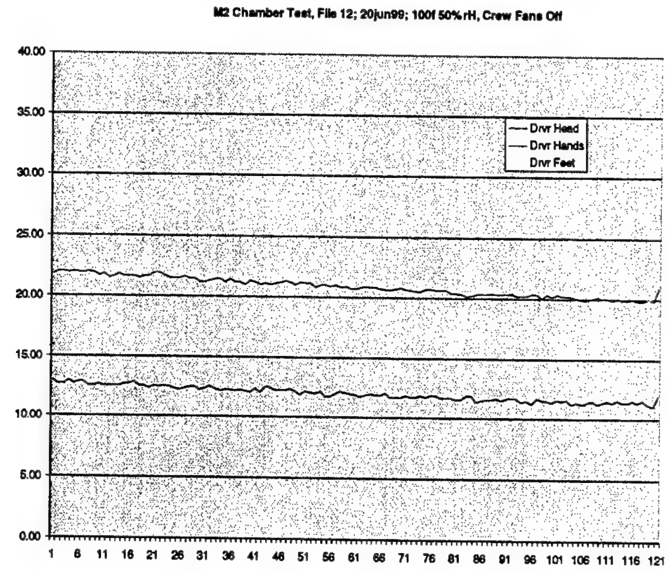


M2A3 Chamber Test; 100° F, 50% rH, fans off

Driver



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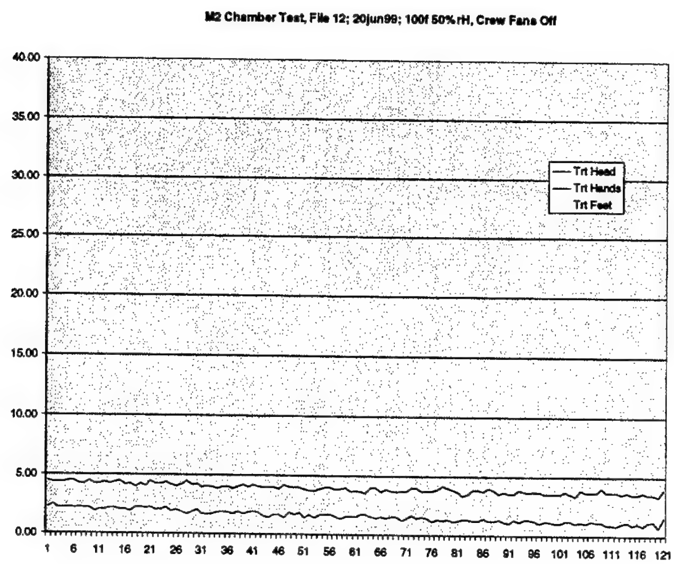

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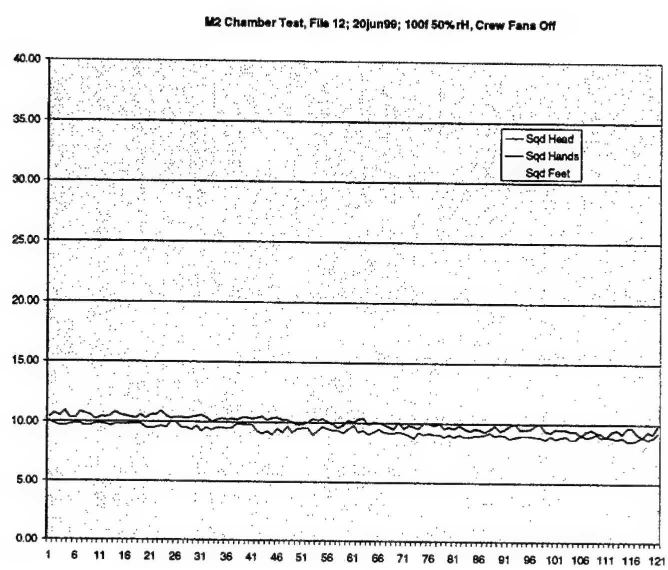
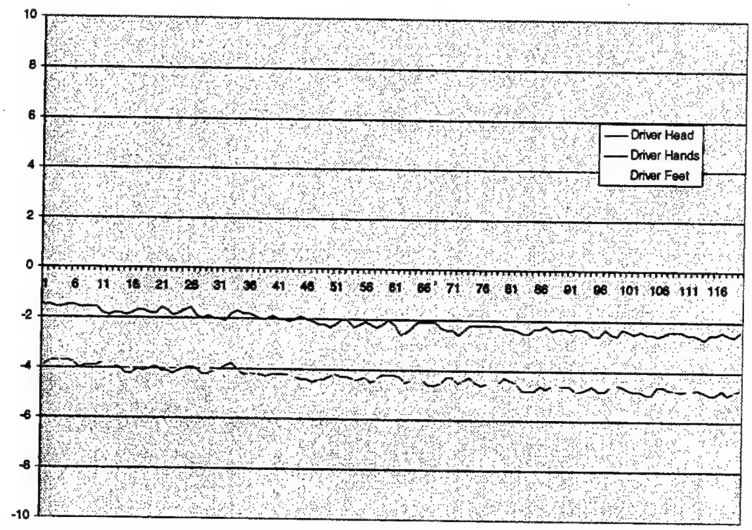


M2A3 Chamber Test; 100° F, 50% rH, fans on

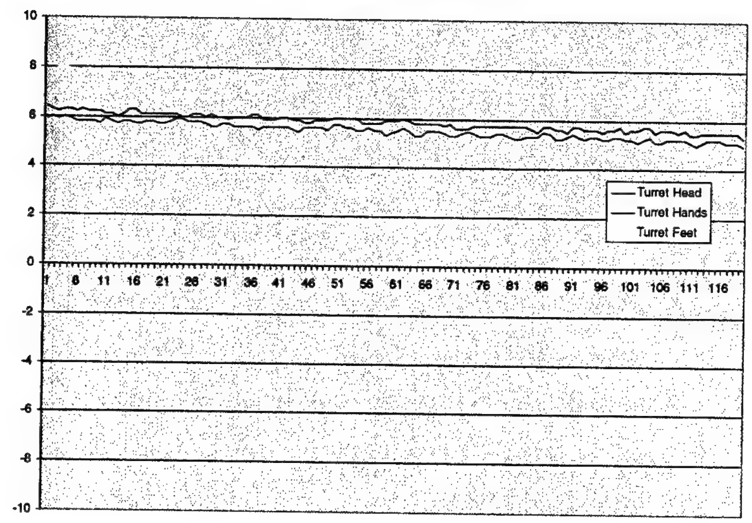
Driver

File14 100F 50rH Fans On



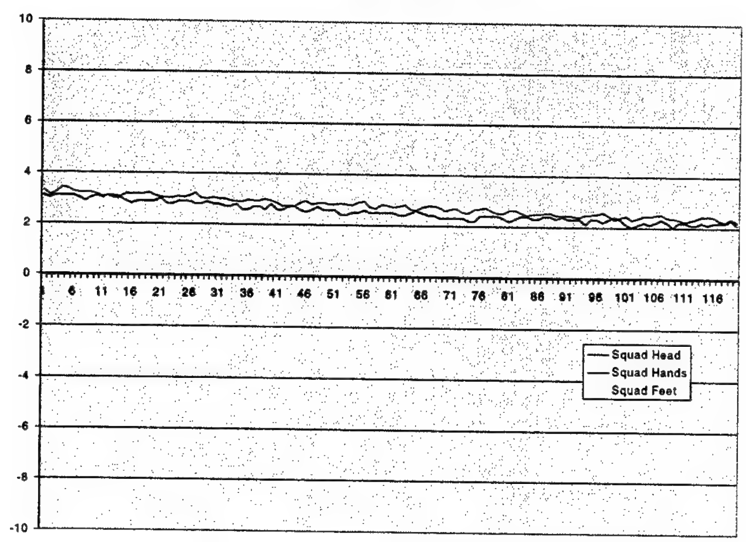
Turret

File14 100F 50rH Fans On



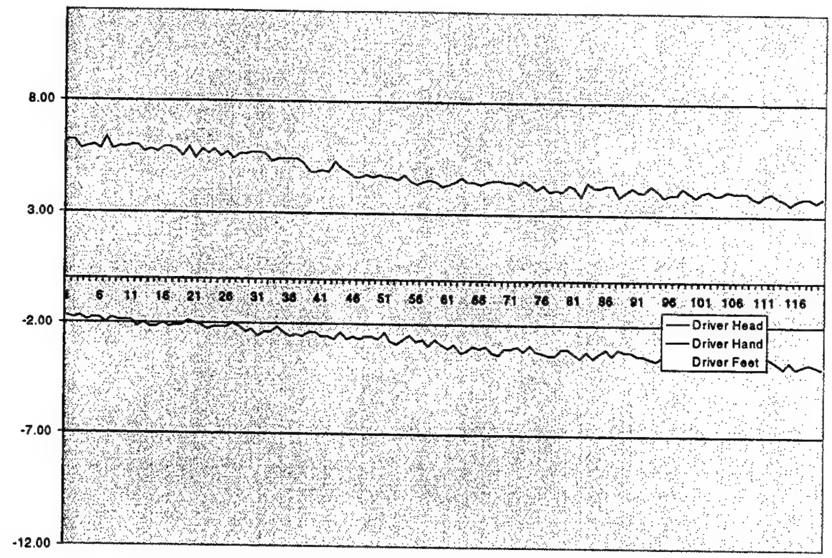
Squad

File14 100F 50rH Fans On

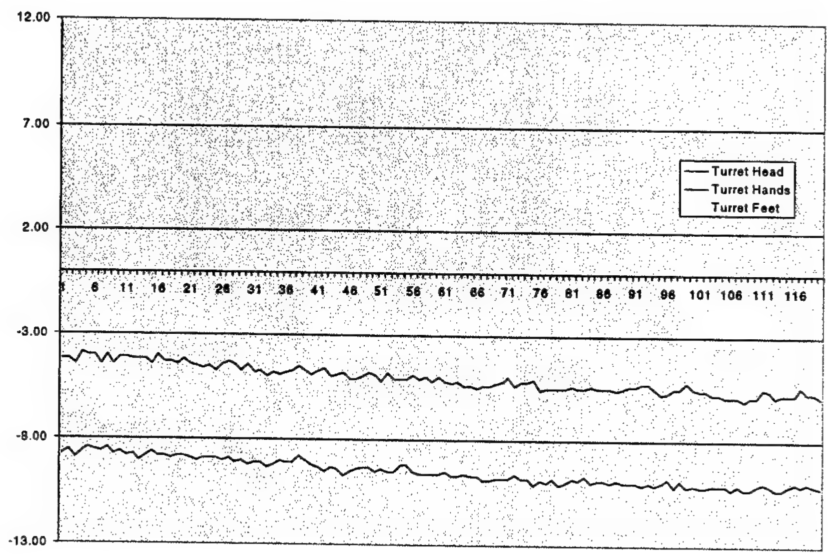


M2A3 Chamber Test; file16; 125° F fans off (delta A3-A2)

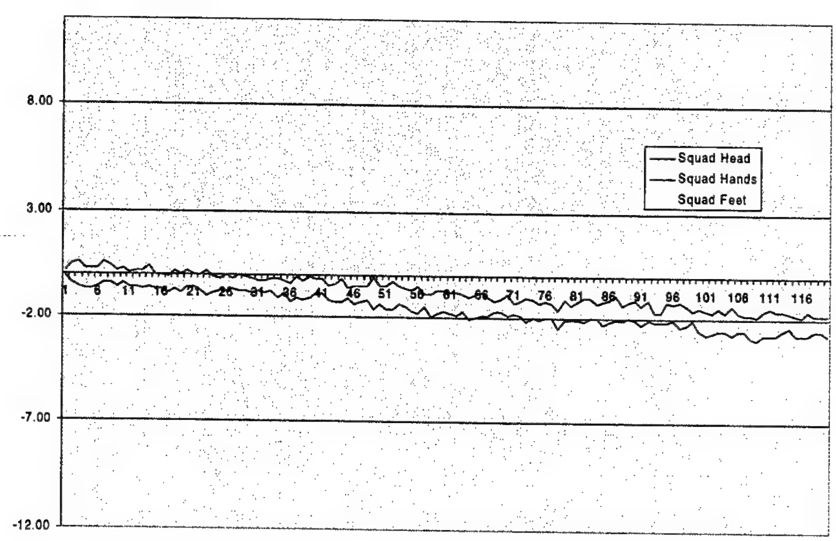
Driver



Turret

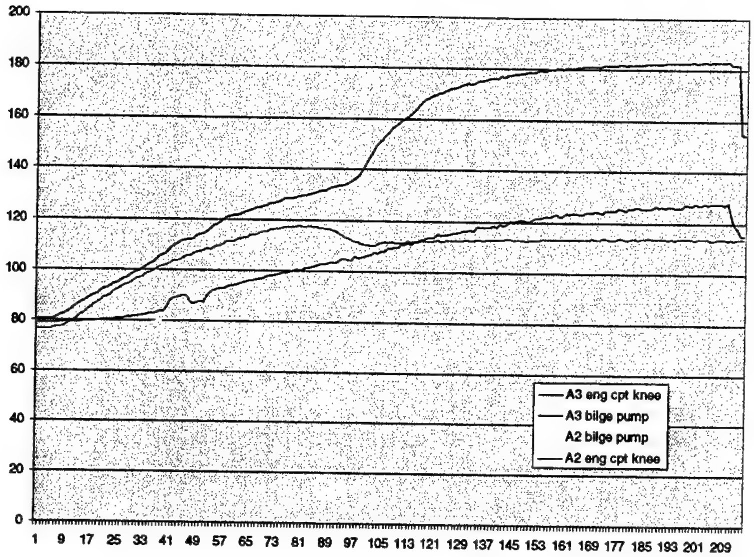


Squad

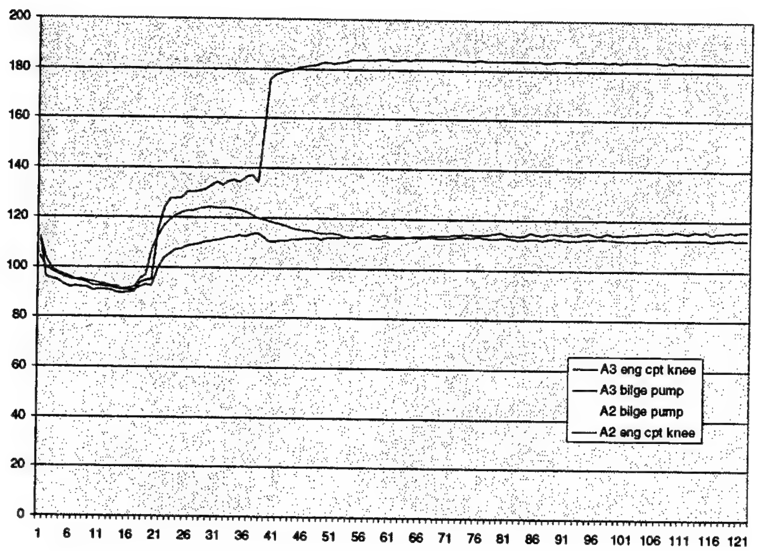


M2A3 Chamber Test; Engineering Excursions

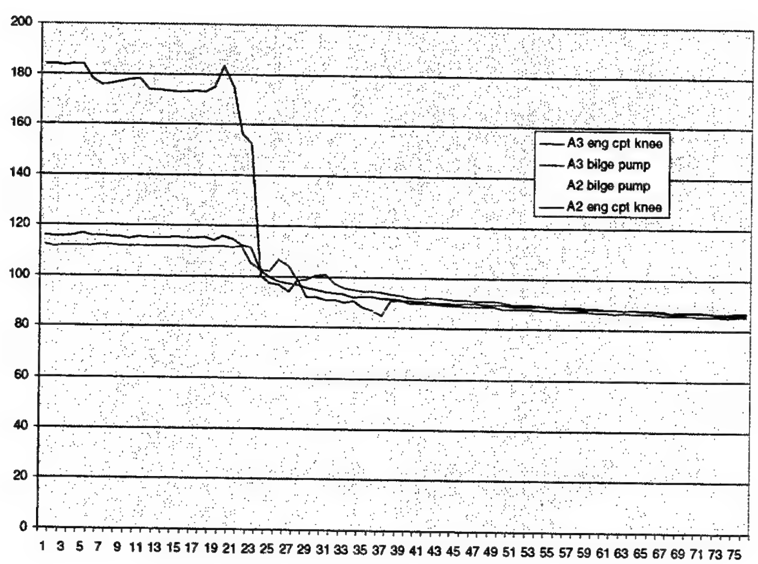
File 23:
Turret Cmdr's &
LRU fan on;
Hull fan off



File 24:
LRU Fan Only on;
Hull Fans off

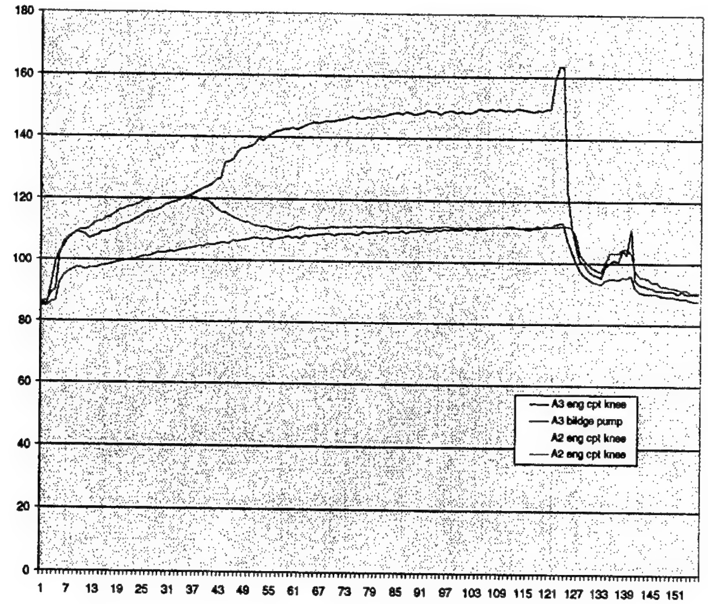


File25:
Turret Cmdr's
& LRU fan on;
Hull fans on

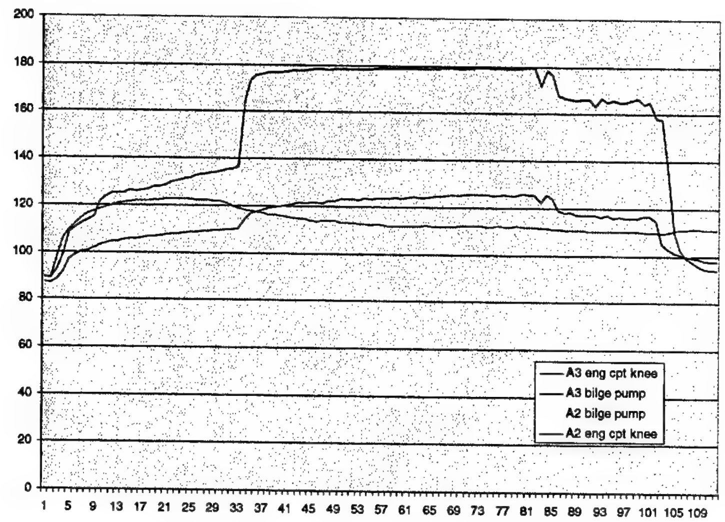


M2A3 Chamber Test; Engineering Excursions (cont.)

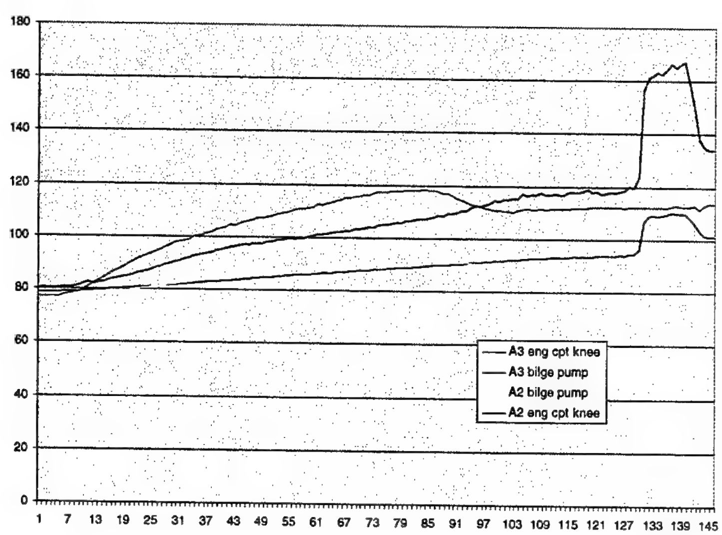
File 26:
Turret Cmdr's &
LRU fan on;
Hull fan on



File 27:
Turret Cmdr's &
LRU fan on;
Hull fans off



File29:
Turret fans off;
Hull fans on;
Turret power on



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13. ABSTRACT *(Maximum 200 words)*

Field data suggested that the Bradley M2/M3 fighting vehicle A3 upgrade subjected the crew to greater heat stress than the previous system did. A study was conducted to determine if the Bradley A3 crew stations were hotter than those of the A2 and if so, what the operational implications were for crew performance.

A Bradley A2 and A3 were place side by side in an environmental chamber and exposed to 30°, 40°, 80°, 100°, and 125° F with the hull fans off; to 80° and 100° F with the hull fans on; and to 80° F with one hull fan on. In addition, the vehicles were exposed to a 10-hour segment of the standard "basic hot" environmental scenario, with hull fans on and off. Finally, the vehicles were run through a series of brief excursions to evaluate engine temperatures. During all testing, temperature data were collected at the driver's station, turret, and squad area at head, hand, and foot heights. Additional sensors recorded relative humidity, pressure, and additional temperatures in the vehicle. Smoke candles were used to evaluate air movement through the vehicles during a side test.

Results showed that temperatures were consistently higher (between 10° and 35° F) in the A3 driver's compartment than in the A2 when the vehicle's hull fans were off. Based on the smoke test, this appears to be caused by the turret fan creating an under-pressure that draws air into the driver's area from the engine.

With the hull fans on, the A3 driver's compartment is between 2° F warmer and 4° F cooler than the A2. The A3 turret is still 5° to 8° warmer. This difference was not operationally significant. At 80° F, both the A2 and A3 were within acceptable limits. At 100° F, both vehicles exceeded recommended heat limits (85° F wet bulb globe temperatures [WBGT]). In the A2, the worst (limiting) locations were driver head and driver hand, with a maximum exposure of 1 hour. In the A3, the worst locations were driver head and turret foot, with a maximum recommended exposure of 1.2 hours.

The conclusion was that the A3 is substantially warmer than the A2 when the hull fan is off but not when the hull fan is on. In environments above 80° F, either vehicle would benefit from reduced internal temperatures.

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